SUNDAY RIVER WATERSHED ASSESSMENT AND PRELIMINARY RESTORATION STUDY

Final Report

Report to: Maine Department of Transportation
16 State House Station
Augusta, Maine 04333-0016

Attention: **Mr. Deane C. Van Dusen**

Report No.: 2003-011
64 Pages, 6 Appendices

Date: April 2004

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APRIL, 2004

PREPARED BY

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EXECUTIVE SUMMARY

Several recent dramatic channel adjustments, concerns over the quality of aquatic habitat and a impetus by agencies and the local community to restore habitat within the Sunday River has lead to this watershed wide assessment. The primary objectives of the study were:

***1. the assessment of the current state of the river, including identification of key processes and root causes of any channel instability*; and,**

2. development of a restoration strategy that prioritizes the areas in the greatest need of stabilization, based on the need to protect private property and infrastructure; in combination with the areas that are the best candidates for success.

In order to satisfy these objectives, the study focused on the primary physical processes that were operative within the watershed. Specifically, the assessment encompassed hydrological, fluvial geomorphological, fisheries, erosion and sediment transport components. Given the strong community interest in the river, the study utilized volunteers in the field data collection as well as hydrological monitoring. Their participation and contribution was invaluable to this assessment, and enabled the collection of data and information over a much broader spatial scale than what would have otherwise been obtained.

The study process started with a review of background information and identification of key issues from the steering committee. Given the recent large channel adjustments there were numerous reports pertaining to the watershed which were beneficial in confirming the scope of the assessment. The next step was rapid assessment of the channel reaches within the watershed. This assessment utilized volunteers with members of the steering committee and consulting team. Before commencing with the field work, a training session was held in an effort to standardize the qualitative nature of the rapid assessments. The next step was reviewing historic aerial photograph information to determine rates of channel adjustment and changes in instream bar deposits. As this was being completed the hydrological field component and geomorphic monitoring work was initiated. The monitoring entailed re-measuring previously established cross-sections, establishing new sections and installing erosion pins. This monitoring enabled quantification of channel adjustments that could be continually measured in the future. The hydrological component involved the installation of stage recorders and the determination of the specific rating curves. In addition to these monitoring sites, staff gages were installed throughout the watershed and guidance was provided to local volunteers to make regular measurements and observations. Detailed field sites were selected to ensure proper representation of the watershed. The selection was based on reach classification and results of the rapid channel assessments. Nine sites were selected and the work was completed by the steering committee, consulting team and volunteers. The remainder of the assessment involved data

synthesis, analyses and interpretation of the results. Based on the findings, a restoration plan, complete with preliminary design concepts was developed.

Specifically, the evolution and adjustments observed in the channels were used in developing locally appropriate and system wide restoration recommendations. In general, periods of land clearing and forestry have left large pulses of sediment in the river system. These pulses are easily reactivated and have resulted in over-wide channels, excessive bank erosion and habitat degradation due to loss of channel variability. Smaller scale bank and bed treatment projects to increase stability of the small and medium streams were identified. These projects are suitable for community volunteer projects. Larger scale projects, such as those proposed for Barker's Brook and at Outward Bound property will require greater expertise and large equipment, and, subsequently, would be more suitable for agency directed restoration projects. The smaller scale projects will improve downstream conditions by reducing sediment loads and will decrease pressures on downstream channels improving channel stability.

Key technical findings from the watershed assessment are of the following:

1. Most of the identified reaches were unstable and experiencing adjustments, based on results from the rapid assessments. Typical adjustments included excessive channel widening and bank erosion with high amounts of locally accumulated sediment. While most reaches were unstable, the quality and health of the reaches, mainly based on aquatic habitat, was reasonably high.

2. The historic assessment indicated that the watershed was regenerating with respect to forest cover. There has also been a substantial increase in riparian vegetation and cover. There were large quantities of stored sediment (bars) within the channel that can be readily re-activated during high flow events.

3. There is a definite gradation of sediment within the channel, with the sediment becoming finer in the downstream direction. This was validated through the detailed field work within the watershed.

4. The relief and energy gradients within the watershed closely match the conceptual pattern described by Schumm. The profile has a distinct concave upwards shape, with the upper reaches of the main stem channel and the main tributaries having relatively steep gradients.

5. The erosion monitoring revealed surprisingly little change. Channel sections established in 2000 by MIFW were re-surveyed with only subtle changes in measured area, depth and bank conditions. The assessment installed new sections and erosion pins in several areas. The repeated measures also revealed little change, with pro-rated annual bank erosion rates of

<0.02ft/yr. This average value accounted for sites experiencing either erosion or deposition/in-filling and omitted the one exceptional value, recorded at the erosion pin upstream of the Covered Bridge, where the measured erosion equated to a rate of ~6ft/yr. The erosion pin results however do not provide a robust estimate of long term trends due to the limited period of monitoring to date.

6. The hydrological assessment relied on collected data throughout the watershed and a surrogate evaluation of the neighbouring Swift River. Based on the measured flows, the response of the Sunday River is quite flashy, with a strong impulse flow.

7. Based on the hydrological analyses, there is some concern regarding the USGS 100-year peak flow that was determined for the Newry Flood Insurance Study. The results indicate that the 100-year flow from the USGS of 7,270 cfs may be 63% lower than the results from the gage data.

8. The sediment budget work indicates that most of the sediment is being derived from the main tributaries. Not only is most of the sediment in the main stem of the Sunday River from the tributaries, the coarser material is also being produced in the upper reaches and from the tributaries.

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1.0 INTRODUCTION

1.1 Purpose

There is little doubt that the Sunday River is a very dynamic river system. Over the last decade, there have been several prominent channel adjustments that have led various agencies to study aspects of the watershed. However, it is felt that there was not a true watershed assessment, which would assess the physical processes operative within the channel valley, which in turn could be used to develop appropriate restoration of the river.

Inherently, these adjustments result in greater risk to private property and structures, poorer aquatic habitat and degraded water quality. In order to effectively restore the river, the underlying cause or factors contributing the channel instability must be understood. The restoration strategy can then address the root or source of the problems. Quite often, the temptation when one encounters a problem on a river, such as high bank erosion rates, is to stop the erosion through various forms of control. However, in many instances, this only addresses the symptom and not the root cause. The result in this scenario is that the erosion control work will eventually fail and can in some cases lead to greater instability at other points in the system. Ensuring the root causes of the observed adjustments are identified along Sunday River is key to developing effective restoration strategies. Using fluvial geomorphology as the central discipline in this approach is necessary, as the discipline, by definition links channel forms with the responsible processes. This understanding will be augmented by insight on the basin hydrology and ultimately, the proposed solutions will be vetted through aquatic biologists to ensure that they are appropriate for the fish assemblage within the river.

1.2 Objectives

A series of objectives were addressed in order to complete the watershed study. They were as follows:

- Assess the current state of the river, including identification of key processes and root causes of the instability.
- Develop a restoration strategy that prioritizes the areas in the greatest need of stabilization, based on the need to protect private property and infrastructure; in combination with the areas that are the best candidates for success.
- All restoration recommendations should address the root cause of the instability, while enhancing aquatic habitat and the riverine ecosystem.

2.0 BACKGROUND REVIEW

It was acknowledged that the Sunday River is a dynamic system that has experienced some substantial adjustments. Accordingly, the watershed has been the subject of numerous, previous studies. Therefore, a background review of past investigations was conducted to assess existing information, thus not duplicating previous efforts. Moreover these observations provide additional insight into the existing and historic conditions within the watershed.

2.1 Mapping and Air Photo Information

A background review was completed using floodplain mapping (US Department of Housing and Urban Development, Floodplain Mapping Scale 1: 2000, 1975), topographic mapping, geological mapping, soil mapping, wetland mapping (US Department of the Interior Fish & Wildlife Service, National Wetland Inventory Mapping Old Speck Mountain, 1:62500, 5/86 Aerial Photo, 1990) and aerial photographs both in small format from 1968 (Scale 1:7920), 1992 (Scale 1:9000), 1999 (Scale 1:9000) and large format from 1943 (Scale 1:9000), 1968 (Scale 1: 7920) and 1992 (Scale 1:9000).

2.2 Existing Reports

Part of the watershed assessment consisted of compiling, reviewing and summarizing background materials associated with the Sunday River watershed. These materials included:

- Bonney, F., Boucher, D. and Howatt, D., 1999. Biological Survey of the Sunday River Fishery Interim Summary Report Series No. 99-5. Maine Department of Inland Fisheries and Wildlife Division of Fisheries and Hatcheries.
- Boucher, D., 1997. Memo: Merrill Brook Impacts.
- Butler, S., 2002. Sunday River Riparian Corridor Assessment, USDA Natural Resources Conservation Service.
- Butler, S., 2002. Public Lands Information for the Sunday River Watershed, Maine, Interdisciplinary Technical Team.
- Chlanda, R., 2002. Sunday River Watershed Assessment, Bethel Maine: Trip Report.
- Maine Department of Inland Fisheries and Wildlife, 1998. Comments – Environmental Project Review.
- Oxford County Soil and Water Conservation District, Sunday River Watershed Steering Committee and the Maine Department of Environmental Protection, 2001. Eastern Sunday River Watershed Survey.

- Oxford County Soil and Water Conservation District, Sunday River Watershed Interest Group and the Maine Department of Environmental Protection, 2003. Western Sunday River Watershed Survey.
- Sunday River Watershed Survey Data Set, year unknown.
- Town of Newry, Oxford County, Maine, 2000. Flood Insurance Study.

The more relevant materials from the aforementioned list are summarized in this section. Bonney et al. (1999) conducted a biological survey of the Sunday River fishery in order to assess the quantity and quality of fish habitat. River morphology was also classified in an effort to determine the overall condition of the river. Approximately 86% of the river area was considered good to excellent habitat for adult and juvenile brook trout, respectively, while thirty percent of the river area was classified as highly sensitive to disturbance through processes such as streambank erosion. Butler (2002) provided a review of the Sunday River riparian corridor in order to identify fish and wildlife habitat components and concerns. In general, the riparian corridor was found to be predominantly composed of mature trees that provide greater than 80% coverage along the stream edge with an average buffer width of at least 35 feet. The corridor was found to be continuous, both up and downstream, by 2 or more stream segments and showed both horizontal and vertical diversity. Finally, essential wildlife habitat elements were in most case found to be readily available to a wide range of fauna. An investigation by Chlanda (2002) evaluated erosion and sedimentation problems in the watershed and provided an assessment of the general geomorphology of the catchment. Historic land use, such as logging, gravel mining, and dam building have all been attributed to the observed accelerated streambank erosion. Furthermore, steep topography across the watershed lends to the potential for excessive erosion during large storm events. Two separate surveys of the Western and Eastern sections of the Sunday River Watershed were established among others by the Oxford County Soil and Water Conservation District (2001 and 2003, respectively) in order to identify sites of soil and sediment erosion. Along the Eastern and Western portions of the catchment 181 and 178 non-point sources of erosion were identified, respectively, and were attributed to eroding stream banks, new channel cutting, roads, and development. Overall, eroded soil and sediment erosion were thought to have impacted or posed a threat to property, agricultural land, fisheries habitat, roads and channel stability. Peripheral materials, including: memos (Boucher, 1997); data sets (Sunday River Watershed Survey, year unknown); Environmental project reviews (Maine Department of Inland Fisheries and Wildlife, 1998); Flood Insurance studies (Town of Newry, Maine, 2000); and Interdisciplinary Resources Technical Team Reports (Butler, 2002) were also reviewed as background material.

In summary, the majority of the Sunday River was considered to be a good to excellent trout habitat, although one-third of the system was classified as sensitive to disturbance such as bank erosion. Historic land use, such as logging, gravel mining, and dam building have all been contributing factors to the observed channel instability and systematic adjustment observed (e.g., streambank erosion). Overall, eroded soil and sediment erosion were thought to have impacted or posed a threat to property, agricultural land, fisheries habitat, roads and channel stability. Although these studies did not link channel form and adjustment to stream process, they did identify several areas of concern with respect to habitat and property.

3.0 BASIN CHARACTERISTICS

Climate and geology are the main aspects of the physical environment that control channel form and process. Geology and physiography act as constraints to channel development and tendency and determine the nature and quantity of sediment available. Climate, in particular precipitation, provides the energy for the system and directly influences basin hydrology and rates of erosion. Land cover and land use are modifying factors which influence the underlying sediment and hydrologic regime.

3.1 Geology

A general understanding of the underlying geology provides insight into the existing channel form. The underlying geology influences the rate of channel change (e.g., migration), the sediment input (i.e., amount and type), and channel geometry. Surficial materials within the Sunday River watershed are composed predominantly of glacial till, glacial outwash and alluvium, which provides substantial sources of coarse sediment. Bedrock outcrops of granite, gneiss and schist are abundant across the catchment, while organic soils are restricted to the lower reaches of the river valleys (Bonney et al., 1999). As a result, sediment and solute sources are likely highly variable in both form and composition. The strength of the parent material and abundance of coarse glacial materials, in part, explain the tendency of the channels to be dominated by coarse sediments.

3.2 Climate

Climate records were unavailable from stations within the Sunday River basin. As a result, climatic norms for the region are based on four stations that position as surrounding nodes to the Sunday River watershed: Rumford, ME (630 ft asl, 44.32°N, 70.32°W); West Paris, ME (540 ft asl, 44.20 °N, 70.35 °W); Berlin, NH (930 ft asl, 44.27°N, 71.11 °W), and; Errol, NH (1280 ft asl, 44.47 °N, 71.08 °W). These normals are summarized in **Table 3.1**. Mean temperatures were available from the Rumford and Berlin automated weather stations and precipitation records were obtained from all four of the stations. The region experiences cold winters and relatively cool summers (Town of Newry, 2003) with an average annual temperature of 43.0 degrees Fahrenheit (°F); ranging from a mean monthly low of 16.1 °F in January to a mean monthly high of 67.3 °F in July. Mean annual precipitation for the region totals 41.8 inches and can be considered relatively consistent year-round. Local orographic effects in the watershed are largely unknown, but the high relief that defines the watershed boundary may influence storm movement and precipitation.

Table 3.1. Climate normals interpolated for the Sunday River watershed from several adjacent stations.

Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temperature (°F)	16.1	19.2	29.1	41.5	53.9	62.7	67.3	65.6	57.0	46.0	35.2	22.3	**43.0**
Total Precipitation (in)	3.23	2.32	3.25	3.42	3.58	3.99	3.66	4.06	3.50	3.83	3.76	3.19	**41.8**

Source: NCDC Clim81, 1971-2000 normals (Issued: November 30, 2001).

3.3 Land Use and Setting

The Sunday River is 13.3 miles long and drains 51.4 square miles of the Mahoosuc Range in Riley Township. The river discharges into the larger Androscoggin River south of its point of origin. The overall drop from headwaters to the Androscoggin River is approximately 2,200 feet with an average slope of 3.9% (Bonney et al., 1999). The watershed is generally steep with few water bodies. There are several tributaries feeding the main branch of the Sunday River. All tend to be steep coarse sediment dominated channels. Land cover is mostly forest, primarily spruce-fir and areas of mixed hardwoods.

Historically, timber harvesting was the dominant land practice across the Sunday River watershed and the state of Maine in general. Log drives were common along the main branch of the Sunday River and major tributaries. Early aerial photographs (1940s) suggest that a substantial portion of the flood plain of the main branch of the Sunday River was being actively farmed. Much of this land has since reverted back to forest as these land uses were abandoned. Only in the lower reaches of the watershed is agriculture still a dominant land practice. In fact, over the last 20 years, primary land use in the watershed has become recreational, initiated by tourism related to the Appalachian Trail and connecting trail systems, Chambers of Commerce, Town and Municipalities, historic sites and scenic attractions. The shift in land practice has placed substantial pressure for further resort development and expansion.

4.0 REACH CHARACTERIZATION

4.1 Reach Delineation

Topographic mapping, geological mapping and aerial photographs were used to understand channel and valley form. Channel form is a product of the flow (magnitude) and the channel materials (sediment type, supply, and bed/bank strength). If one of these is altered, the channel adjusts its form to retain or find a new 'dynamic equilibrium'. The characteristics of the flow or channel materials can change along a brook, stream or river. In order to account for these changes, channels are separated into reaches – normally several hundred yards to a couple miles in length. A reach displays similarity with respect to its physical characteristics, such as channel form, function, and valley setting. Delineation of a reach considers sinuosity, gradient, hydrology, local geology, degree of valley confinement, and vegetative control using methods outlined in PARISH Geomorphic Ltd. (2001). Based on measurements of channel sinuosity, relative gradient, valley form, geology, and channel reaches were identified for the channels within the Sunday River watershed (**Figure 4.1**, **Table 4.1**). Reach boundaries were confirmed during a reconnaissance walk and a review of aerial photographs. Reaches were subsequently characterized by stream type using the morphological classification system outlined in Rosgen (1996) (**Table 4.1**). A long profile of the Sunday River and its tributaries is provided in **Figure 4.2** in order to place the gradients in context.

There is a substantial range in gradients and sinuosity values. Generally, the lower order streams have higher gradient and lower sinuosity, while the higher order streams tend to have a lower gradient and higher sinuosity features. This is characteristic of mountainous watersheds. Conceptually drainage systems can be divided into zones, headwater, transfer and depositional, from upstream to downstream dependent on dominant form and function (see **Figure 4.3**). Headwater (production) zones are characterized by steep gradients, little in the way of alluvial storage and floodplain, and net loss or production of sediment which is transported to the downstream channels. Transfer zones are characterized by wide floodplains, moderate gradients and meandering channel patterns. The floodplains provide areas for temporary storage of sediment. Generally, there is no net gain in sediment within the system. Further downstream, the depositional zone is characterized by "flat" gradient, strong meandering pattern and net sediment storage. From the gradients and sinuosity values provided in **Table 4.1** the Sunday River appears, at least from a form perspective, to fit this conceptual model.

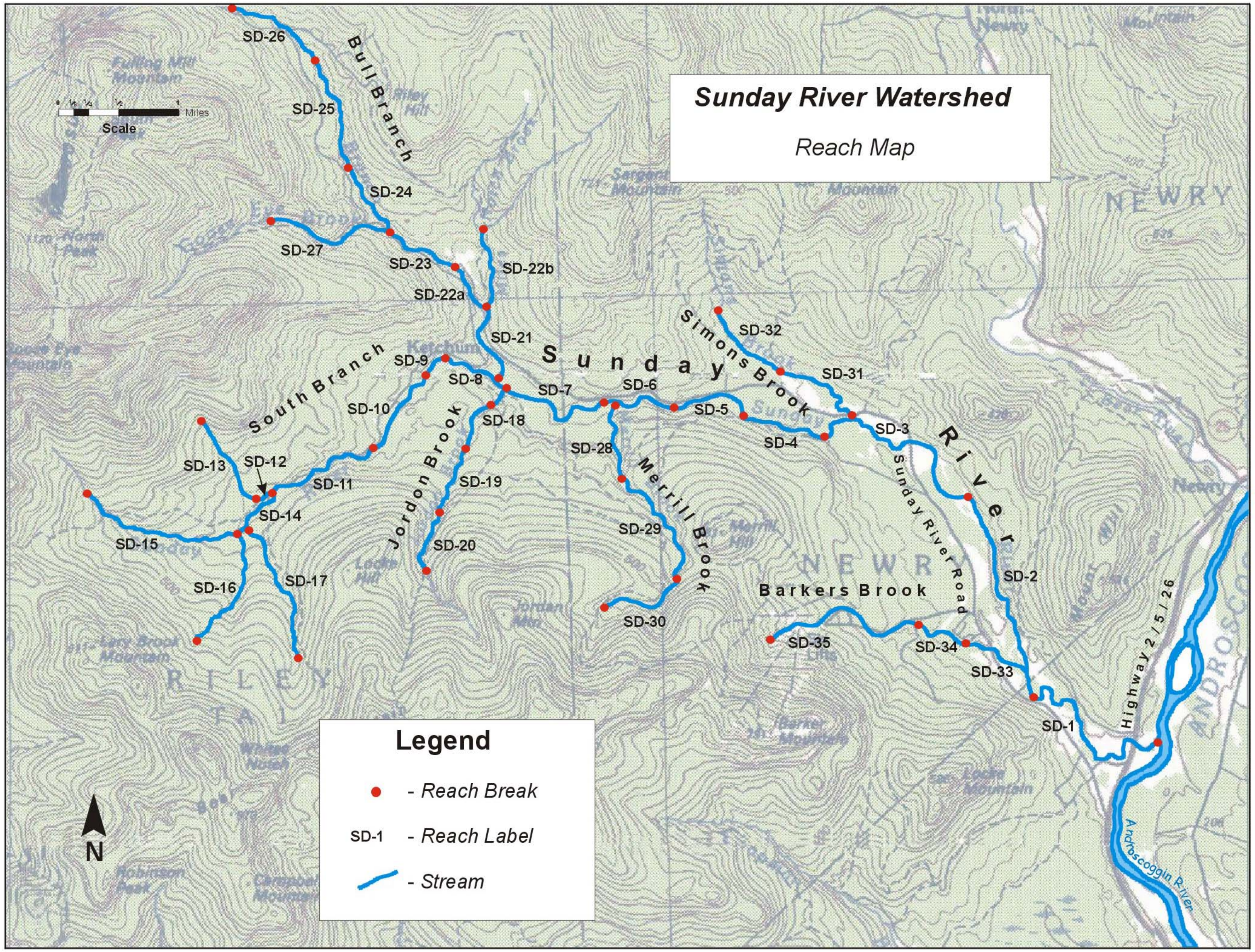


Figure 4.1. Reach breaks.

Table 4.1. Reach characteristics.

Reach Name	Stream Order	Length (ft)	Gradient (%)	Sinuosity	Stream Type
SD-1	4	10037	0.04	1.58	E
SD-2	4	10207	0.28	1.07	F
SD-3	4	10142	0.32	1.11	C
SD-4	4	3057	0.92	1.02	C
SD-5	4	3854	0.91	1.01	G
SD-6	4	3493	1.49	1.02	B
SD-7	4	5494	0.96	1.21	C
SD-8	4	2827	2.19	1.02	B
SD-9	4	1335	1.72	1.06	B
SD-10	4	4198	1.95	1.03	B
SD-11	4	5235	3.06	1.04	B
SD-12	3	846	2.25	1.01	B
SD-13	2	4497	9.38	1.00	A
SD-14	3	2509	1.79	1.06	G
SD-15	2	7692	8.26	1.01	A
SD-16	2	5888	11.89	1.02	Aa+
SD-17	2	7111	7.09	1.05	A
SD-18	3	2683	5.22	1.11	A
SD-19	3	3516	8.30	1.06	A
SD-20	3	3772	7.24	1.02	A
SD-21	3	3916	2.40	1.06	B
SD-22a	3	3067	2.32	1.03	B
SD-22b	2	3979	4.73	1.04	B
SD-23	3	2942	3.50	1.03	B
SD-24	2	3697	3.79	1.03	B
SD-25	2	5448	4.66	1.02	A
SD-26	2	4002	4.67	1.01	A
SD-27	2	5999	7.23	1.01	A
SD-28	2	3506	7.19	1.03	A
SD-29	2	6281	7.01	1.07	A
SD-30	2	3746	5.95	1.01	A
SD-31	2	4175	1.27	1.17	C
SD-32	2	4533	2.07	1.03	B
SD-33	3	3936	0.93	1.12	C
SD-34	3	2178	2.62	1.12	B
SD-35	2	7455	7.32	1.02	A

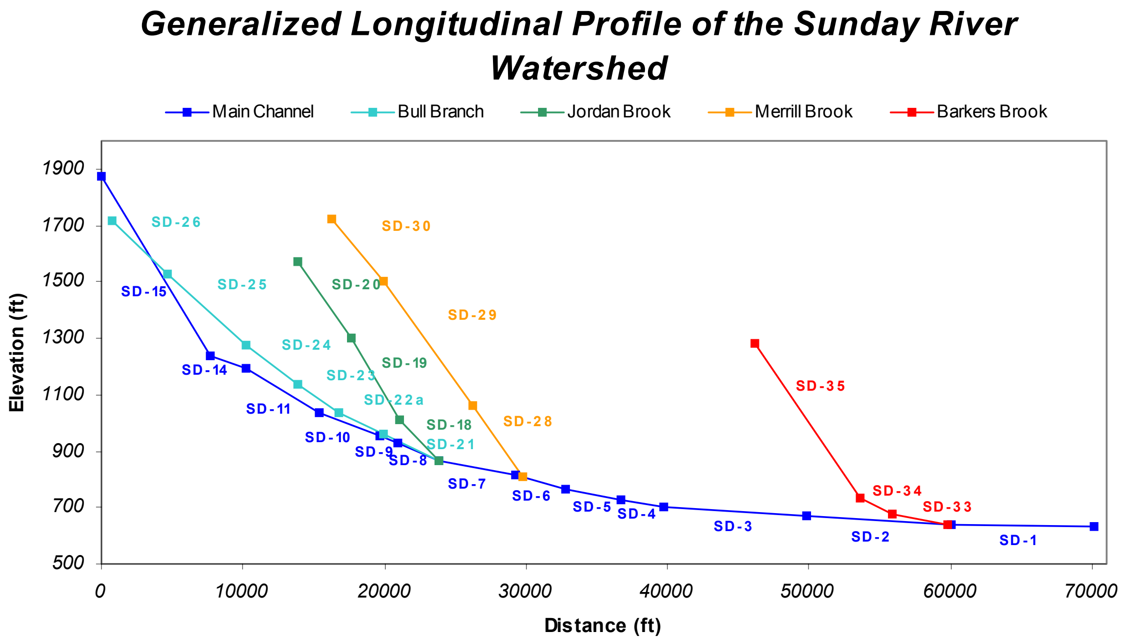


Figure 4.2. Long profile of the Sunday River and its tributaries.

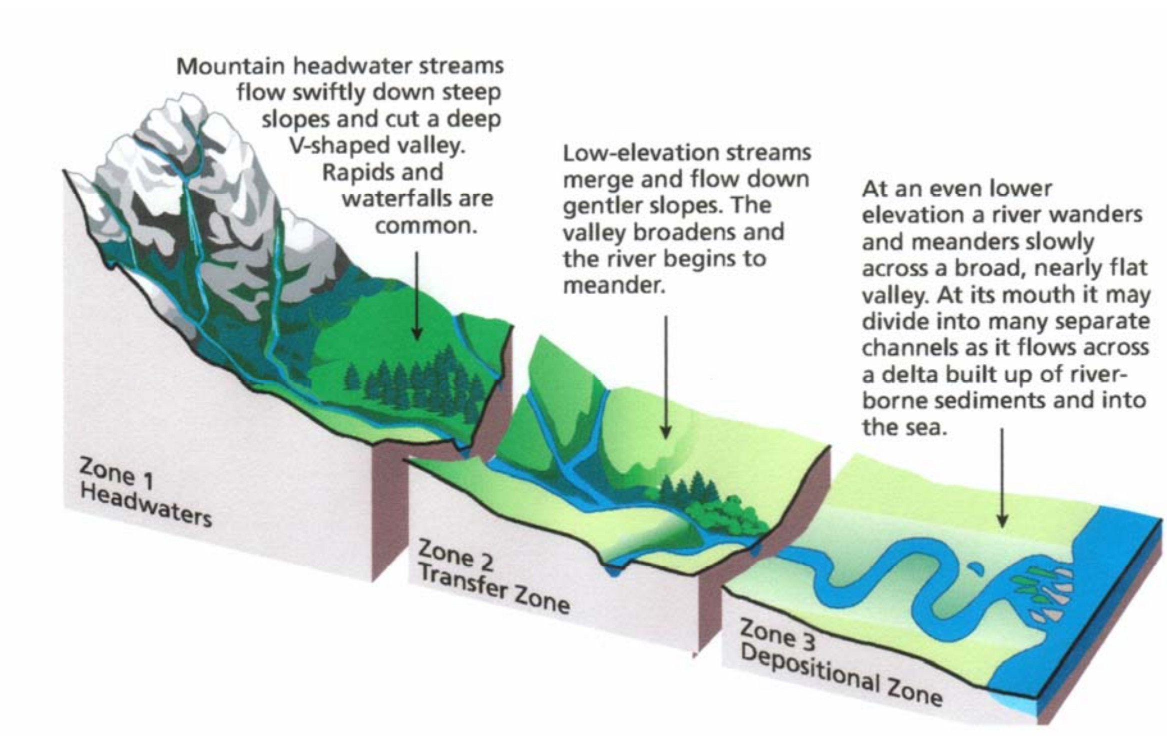


Figure 4.3. Conceptual zones within a steep drainage basin (Miller, 1980 in USDA, 1997)

4.2 Rapid Reach Assessment

During field reconnaissance, all reaches were walked and rapid assessments were completed (e.g. Rapid Geomorphic Assessment (RGA), Rapid Stream Assessment Technique (RSAT) and The Habitat Assessment Field Data Sheet) with any areas of substantial erosion being noted. Additionally, semi-quantitative measures of bankfull channel dimensions, type of substrate, vegetative cover, and channel disturbance were completed.

4.2.1 Approach / Methods

A Rapid Geomorphic Assessment documents observed indicators of channel instability (Ontario Ministry of Environment, 1999). Observations are quantified using an index that identifies channel sensitivity based on evidence of aggradation, degradation, channel widening and planimetric adjustment. The index produces values that indicate whether the channel is stable/in regime (score <0.20), stressed/transitional (score 0.21-0.40) or adjusting (score >0.41). An RSAT provides a broader view of the system by also considering the ecological functioning of the stream (Galli, 1996). Observations include instream habitat, water quality, riparian conditions, and biological indicators. RSAT scores rank the channel as maintaining a low (<20), moderate (20-35) or high (>35) degree of stream health. It should be noted that stability and stream health are not synonymous. Although these parameters are linked, streams can potentially have lower stability scores but a higher stream health value. The Habitat Assessment Field Data Sheet, better known as a HABSCORE, was produced by Environmental Protection Agency to scientifically assess habitat and stream conditions. The HABSCORE is a ranked system which accounts for instream substrate, active processes, channel complexity and riparian conditions. The ranked scores are converted to a percentage of the score from a representative, reference or ideal local reach. This provides a relative measure of local stream health with respect to a reference reach. In this case, the reach with the highest score was defined as the reference reach. It should be noted that the reach with that the highest HABSCORE does not mean that the reach is ideal; it only means that it had the highest cumulative score from all the reaches studied. Due the number of volunteer groups and variation in interpretation it is expected that there would be greater variability in scores than would be encountered if all the assessments were conducted by a single experienced team.

4.2.2 Results

Semi-quantitative measures of bankfull channel dimensions, type of substrate, vegetative cover, and channel disturbance collected during the rapid assessment are provided in **Table 4.2**. The information provided is, in many cases, verbatim descriptors of field notes taken by the volunteers. In cases where field sheets were incomplete missing descriptors were marked with N/A. As the values provided were obtained during the rapid assessments with many of the observations being collected by volunteers of whom had limited experience in interpreting field indicators of bankfull, estimate dimensions of the bankfull condition should be considered rough approximations. Still, these values provide a general indication of the scale of channels between reaches within the watershed. Generally, a trend of sediment fining, and increasing bankfull channel size occurred in the downstream direction. Furthermore, much of the watershed still has substantial riparian cover. Photographs were also taken along most reaches providing a visual record of reach conditions (selected photographs are compiled in **Appendix A**). **Table 4.3** provides a summary of the rapid assessment measures and **Figures 4.4** to **4.6** show their spatial distribution. Overall, most of the channels showed some signs of adjustment and most were in adjustment or transition. This is likely, in part, due to historic land use.

Table 4.2. Summary of qualitative reach observations collected during rapid assessment program.

Reach #	Stream Order	Bankfull Width (ft)	Bankfull Depth (ft)	Substrate Type	Bank Materials	Riparian Vegetation
SD-1	4	~ 100 ft	~ 5 ft	Sand, grv	Sand, grv	Hardwoods, ferns
SD-2	4	100 – 200 ft	~ 6 ft	Sand, grv	Sand, grv	Hardwoods, shrubbery
SD-3	4	75 – 100 ft	10 – 15 ft	Cob, grv, sand	Cob, sand, soil	Mixed species
SD-4	4	~ 100-150 ft	6 – 7 ft	Bdr, bldr, cob, grv	Cob, grv, sand	Mixed forest
SD-5	4	~ 115 ft	~ 3 ft	Grv to Bldr	Sa/cob/grv	Mixed forest
SD-6	4	60 – 80 ft	3 – 6 ft	Cobble	Glacial Till	Varied
SD-7	4	10 – 75 ft	3 – 6 ft	Grv to Cob	Till	Natural
SD-8	4	~ 35 ft	3 – 6 ft	Bdr, bldr, cob, grv	Till	Variety
SD-9	4	N/A	N/A	Bdr, cob, grv	N/A	N/A
SD-10	4	N/A	N/A	Bdr, Some bldr, cob, grv	N/A	N/A
SD-11	4	N/A	N/A	Bldr, cob, grv	N/A	N/A
SD-12	3	~ 15 ft	3 – 3.5 ft	Cob, grv	Cob, grv	Mixed hardwood
SD-13	2	8 – 10 ft	3 – 4 ft	Bdr, bldr, cob, grv	Bdr, bldr, cob	Mixed forest
SD-14	3	~ 50 ft	~ 8 ft	Bldr, cob, grv	Grv, cob, sand	Mixed hardwood
SD-15	2	15 – 45 ft	4 – 5 ft	Bldr, cob, grv	Clay and cobble	Mixed hardwood and softwood
SD-16	2	~ 30 ft	~ 3 ft	Ledge, cob, grv	Cobble	Mixed hardwood
SD-17	2	35 – 40 ft	3 – 4 ft	Ledge, cob, grv	Cobble	Mixed hardwood
SD-18	3	20 – 60 ft	6 – 13 ft	Bldr, cob, grv	Bldr, cob	Mixed hardwood
SD-19	3	~ 45 ft	~ 5 ft	Bldr, cob	Bldr, cob	Trees
SD-20	3	~ 30 ft	~ 3 ft	Bldr, cob	Bldr, cob	Hardwoods
SD-21	3	~ 51 ft	~ 1.5 ft	N/A	Grv, cob	Trees
SD-22a	3	~ 53 ft	3 – 7 ft	Ledge, cob	Ledge, soil	Mature, young trees
SD-22b	2	~ 54 ft	3 – 11 ft	Cobble	Bldr, cob, grv	Trees

Reach #	Stream Order	Bankfull Width (ft)	Bankfull Depth (ft)	Substrate Type	Bank Materials	Riparian Vegetation
SD-23	3	~ 51 ft	N/A	Bdr, cob	Bdr, cob, grv	Trees, bushes
SD-24	2	~ 50 ft	~ 7 ft	Ledge, cob	Cobble	Mixed hardwood
SD-25	2	–	–	–	–	–
SD-26	2	–	–	–	–	–
SD-27	2	~ 50 ft	5 – 6 ft	Cobble	Bdr, bldr	Mixed forest
SD-28	2	30 – 40 ft	2 – 3 ft	Bdr, cob, grv	Cob, grv	Mixed forest
SD-29	2	N/A	N/A	N/A	N/A	N/A
SD-30	2	N/A	N/A	N/A	N/A	N/A
SD-31	2	12 – 15 ft	~ 3 ft	Cobble	N/A	Mixed species
SD-32	2	~ 12 ft	~ 1 ft	Cob, grv	N/A	Mixed species
SD-33	3	~ 15 ft	2 – 3 ft	Cob, grv	Cob, grv, sand	Hardwoods
SD-34	3	20 – 25 ft	2 – 3 ft	Cob, grv	Cob, grv, sand	Hardwood
SD-35	2	10 – 15 ft	2 – 3 ft	Bldr, cob, grv, bdr	N/A	Mixed hardwood

Table 4.3. Rapid assessment scores for all reaches.

Reach	Completion Date	RSAT	RGA	HABSCORE (Total)	HABSCORE (%)
1	June 4, 2003	21	0.59	86	48.0
2	June 4, 2003	24	0.52	95	53.1
3	June 4, 2003	30	0.72	125	69.8
4	June 4, 2003	30	0.32	135	75.4
5	June 5, 2003	27	0.37	118	65.9
6	June 5, 2003	42	0.45	149	83.2
7	June 5, 2003	35	0.38	149	83.2
8	June 5, 2003	39	0.23	163	91.1
9	June 5, 2003	33	0.37	137	76.5
10	June 5, 2003	29	0.59	128	71.5
11	June 5, 2003	30	0.5	139	77.7
12	June 4, 2003	40	0.31	154	86.0
13	June 4, 2003	41	0.47	175	97.8
14	June 4, 2003	29	0.66	127	70.9
15	June 5, 2003	33	0.65	144	80.4
16	June 5, 2003	35	0.57	163	91.1
17	June 5, 2003	35	0.41	166	92.7
18	June 3, 2003	35	0.45	179	100.0

Reach	Completion Date	RSAT	RGA	HABSCORE (Total)	HABSCORE (%)
19	June 3, 2003	40	0.37	142	79.3
20	June 3, 2003	39	0.33	155	86.6
21	June 3, 2003	44	0.48	164	91.6
23	June 4, 2003	45	0.45	162	90.5
24	June 3, 2003	39	0.23	174	97.2
25	Not accessible	–	–	–	–
26	Not accessible	–	–	–	–
27	June 3, 2003	41	0.26	176	98.3
28	June 3, 2003	23	0.71	131	73.2
29	June 3, 2003	27	0.63	132	73.7
30	June 3, 2003	34	0.5	133	74.3
31	June 4, 2003	33	0.57	151	84.4
32	June 4, 2003	35	0.48	149	83.2
33	June 4, 2003	26	0.49	105	58.7
34	June 4, 2003	31	0.35	133	74.3
35	June 4, 2003	29	0.51	123	68.7
22a	June 4, 2003	45	0.37	163	91.1
22b	June 3, 2003	33	0.47	153	85.5

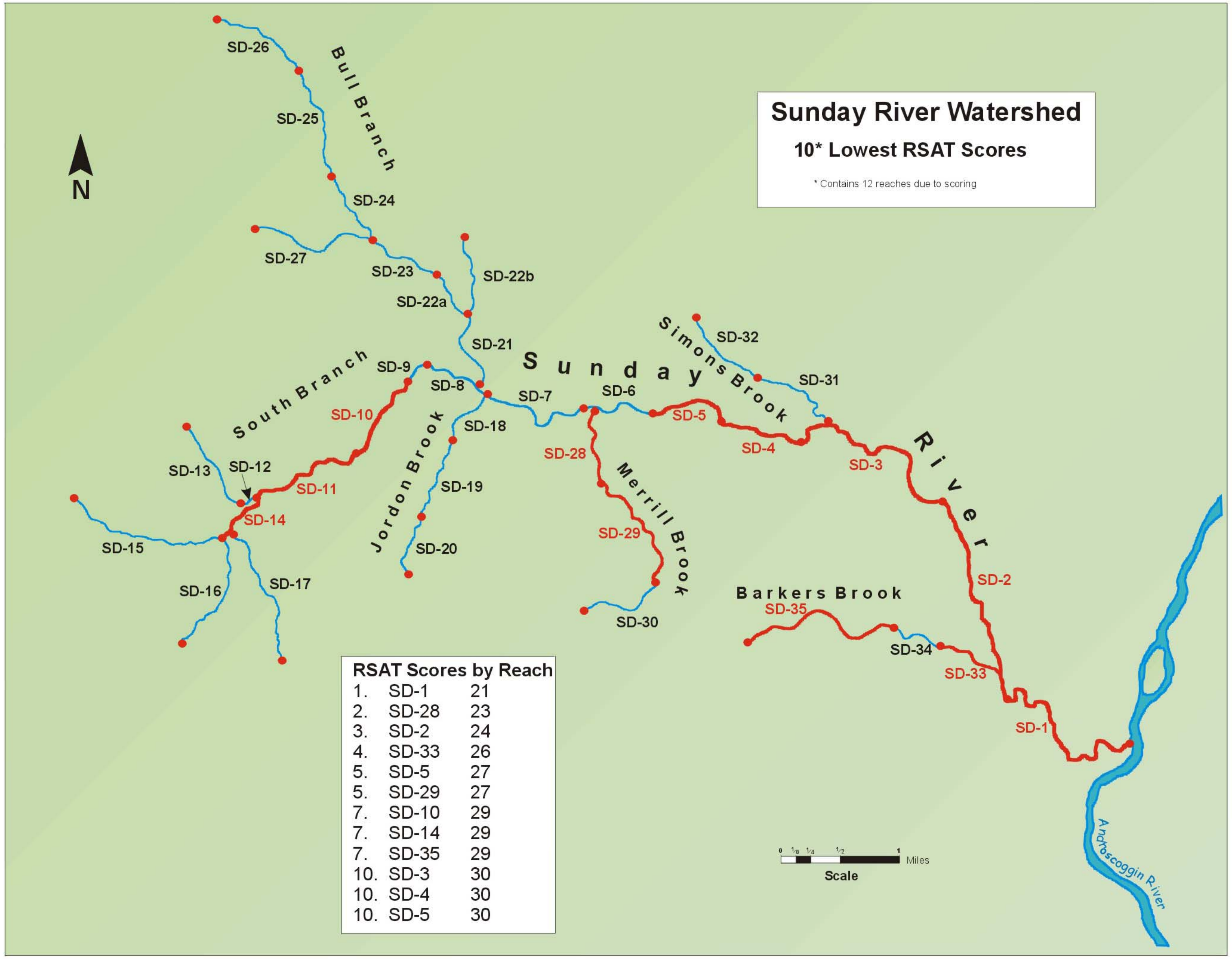
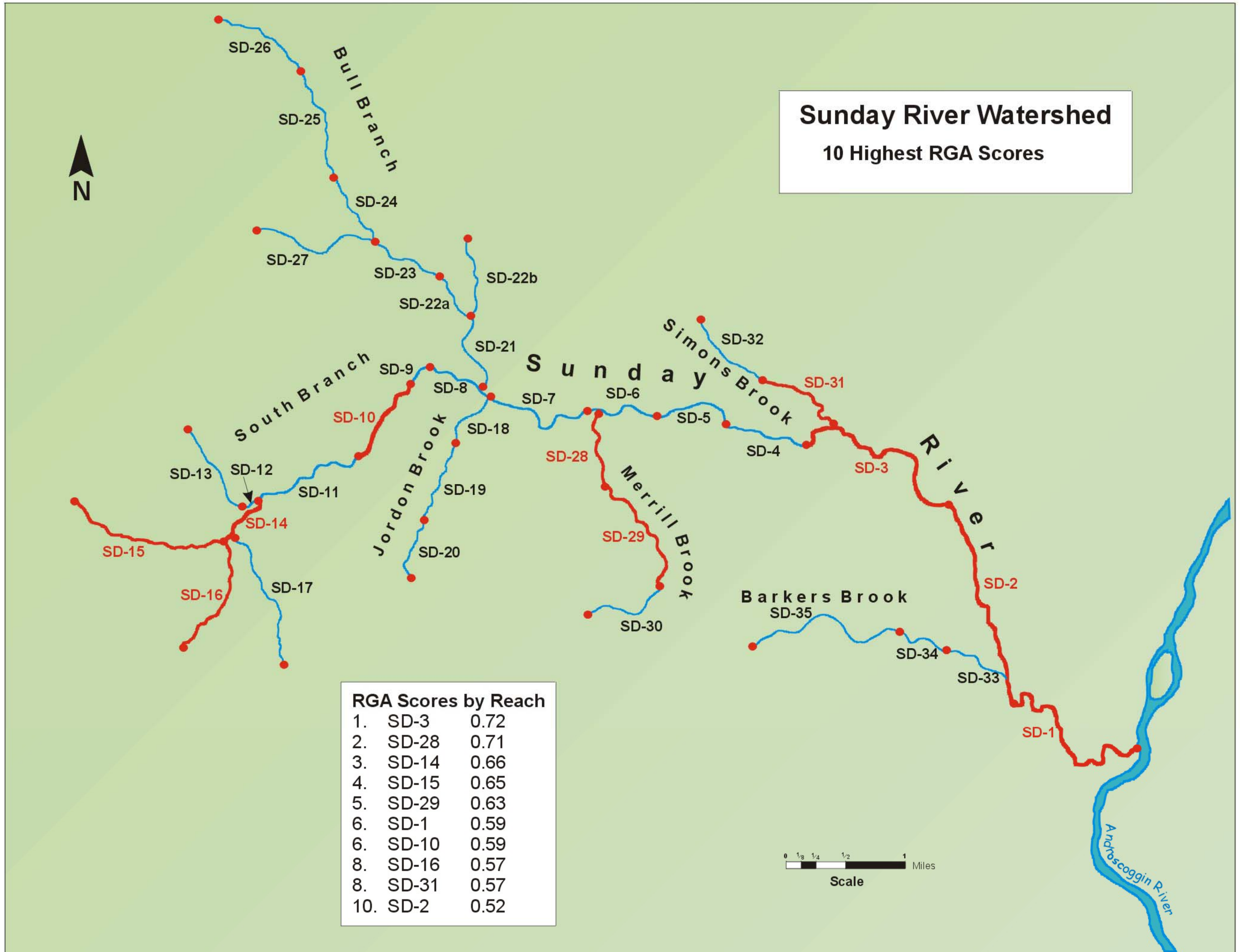


Figure 4.4. Top ten reaches of the Sunday River with the lowest RSAT scores based on the rapid assessments.



1.	SD-3	0.72
2.	SD-28	0.71
3.	SD-14	0.66
4.	SD-15	0.65
5.	SD-29	0.63
6.	SD-1	0.59
6.	SD-10	0.59
8.	SD-16	0.57
8.	SD-31	0.57
10.	SD-2	0.52

Figure 4.5. Top ten reaches of the Sunday River with the highest (unstable) RGA scores based on the rapid assessments.

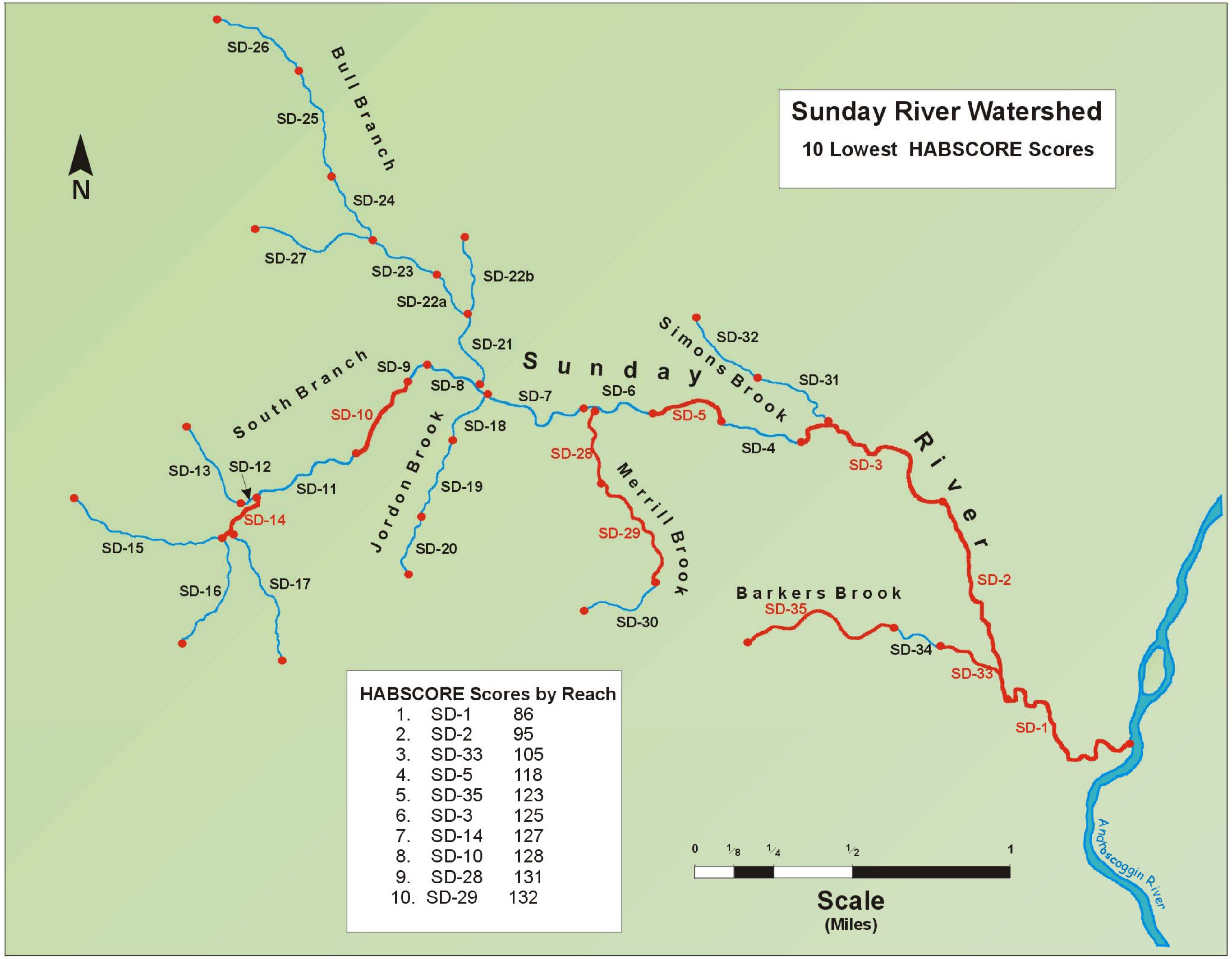


Figure 4.6. Top ten reaches of the Sunday River with the lowest HABSCORE scores based on the rapid assessments.

Rarely can geomorphic form and function be considered homogenous across a given watershed area. From a spatial context, a stream catchment can be differentiated into zones of sediment production, transport and deposition. However, before making these broader classifications, it is useful to make geomorphic characterizations of specific stream courses that contribute to the overall watershed.

The south branch showed planimetric form adjustment within the lower reaches and substantial widening in the upper areas. In almost all cases, the Sunday River scored high RGA scores indicating a system in transition, while RSAT scores assessed the stream to be in moderate condition. The substrate of the channel was gravelly with both cobble and boulders predominating with a riparian zone composed primarily of hardwood forest. The Bull Branch exhibited a wide range of geomorphic processes, including aggradation, degradation and widening and moderate to high stability scores. The upper portion of the branch showed transition while the lower sections displayed adjustment. The channel substrate was composed of primarily cobbles, boulders and bedrock and hardwood forest predominated the riparian zones. Jordan Brook showed transition with high degrees of both aggradation and planimetric form adjustment. The RSAT scored the stream as having a high degree of stream health. This being said, it does not imply that Jordon Brook should be used as a reference. Portions of Jordon Brook were noted to be unstable (RGA of 0.45 for SD-18). Reaches along Merrill Brook scored some of the highest RGA scores in the watershed, displaying considerable aggradation; however, also showing large amounts of degradation, widening and planimetric form change, suggesting a highly dynamic system in adjustment. Both channel substrate and riparian zone characteristics for Jordan and Merrill Brooks were similar to the aforementioned upstream branches of the Sunday River. The lower section of the main Sunday River channel, including both Barkers and Simons Brooks, exhibited mostly aggradation, with examples also of widening and planimetric form adjustment. Channel substrate materials were found to be sand and gravels, and vegetation was hardwood forest with sporadic sections of pasture. The RGA on the upper portion of the Main Sunday River denoted examples of mostly widening and considered these reaches to be in transition, while RSAT scores showed stability to be moderate to high. Channel substrate was a combination of sand and cobbles, while vegetation was primarily hardwood.

Finally, it should be reiterated that these results were obtained using qualitative techniques by crews comprised of volunteers with limited experience and only one day of formal training. The results do provide a basin wide indication of active processes and channel conditions. However, ultimately, the results are subjective to the crew that conducted the work. For instance, on Jordon Brook, one crew assessed all three reaches (SD 18, 19, 20) and the RGA, RSAT and HABSCORE appear to indicate that while there were some stability issues on a basin scale, conditions along the tributary are some of the better in the watershed. This finding is considered questionable though based on the background review and input from the Steering Committee. On the other hand, in looking more closely into the results, the volunteer crew clearly noted that SD-18 was in poorer condition that the two upstream reaches and this finding does match with photographic evidence and previously completed background work. Thus, if work were to be undertaken on Jordon Brook, it should be focused on the downstream reach. This is an example of how the rapid assessments can be effectively evaluated.

To gain an overall pattern of the dominant adjustments within the watershed, the dominant (primary) and secondary systematic adjustments noted from the Rapid Geomorphic Assessments are presented in **Figures 4.7** and **4.8**. The following general patterns were observed. First, there was an apparent linkage between aggradation and widening, especially in lower (main channel) reaches of the watershed. The channel widening is likely a product of the channel attempting to retain its cross-sectional area even with systematic infilling. Second, aggradation is either the primary or systematic adjustment along all reaches of main channel, except SD-6 where channel widening and planimetric adjustment dominated (even though there was considerable evidence of aggradation). Third, another dominant process observed along the main branch was widening.

Three general trends appeared along the tributaries of the Sunday River. First, there was a linkage between degradation and widening, indicating that reaches have a capacity and competency to erode and transport bed and bank sediments within the reach and those transported to the reach from upstream sources (characteristic of headwater or production zones). Second, there were reaches where widening and aggradation dominated, indicating that reaches could erode their banks but without competency to transport sediment through the system. This may also indicate an oversupply of sediment and an attempt by the channel to maintain cross-sectional area. The third pattern was reaches displaying evidence of degradation and aggradation. This is likely an indication of dynamic bedload dominated channels which are actively eroding and transporting sediment through 'pulses' (i.e. bars and other depositional features).

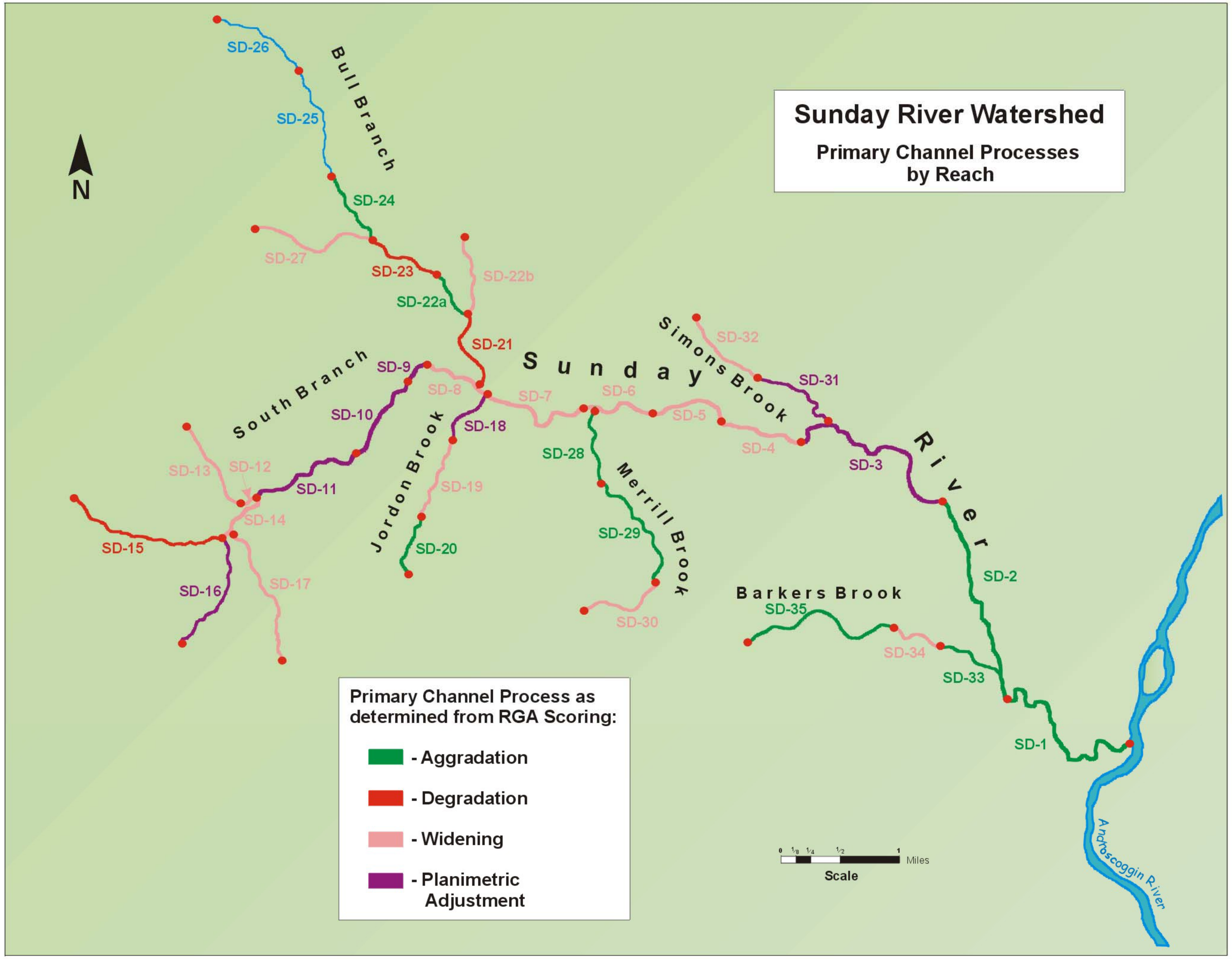


Figure 4.7. Primary processes as identified by Rapid Geomorphic Assessment.

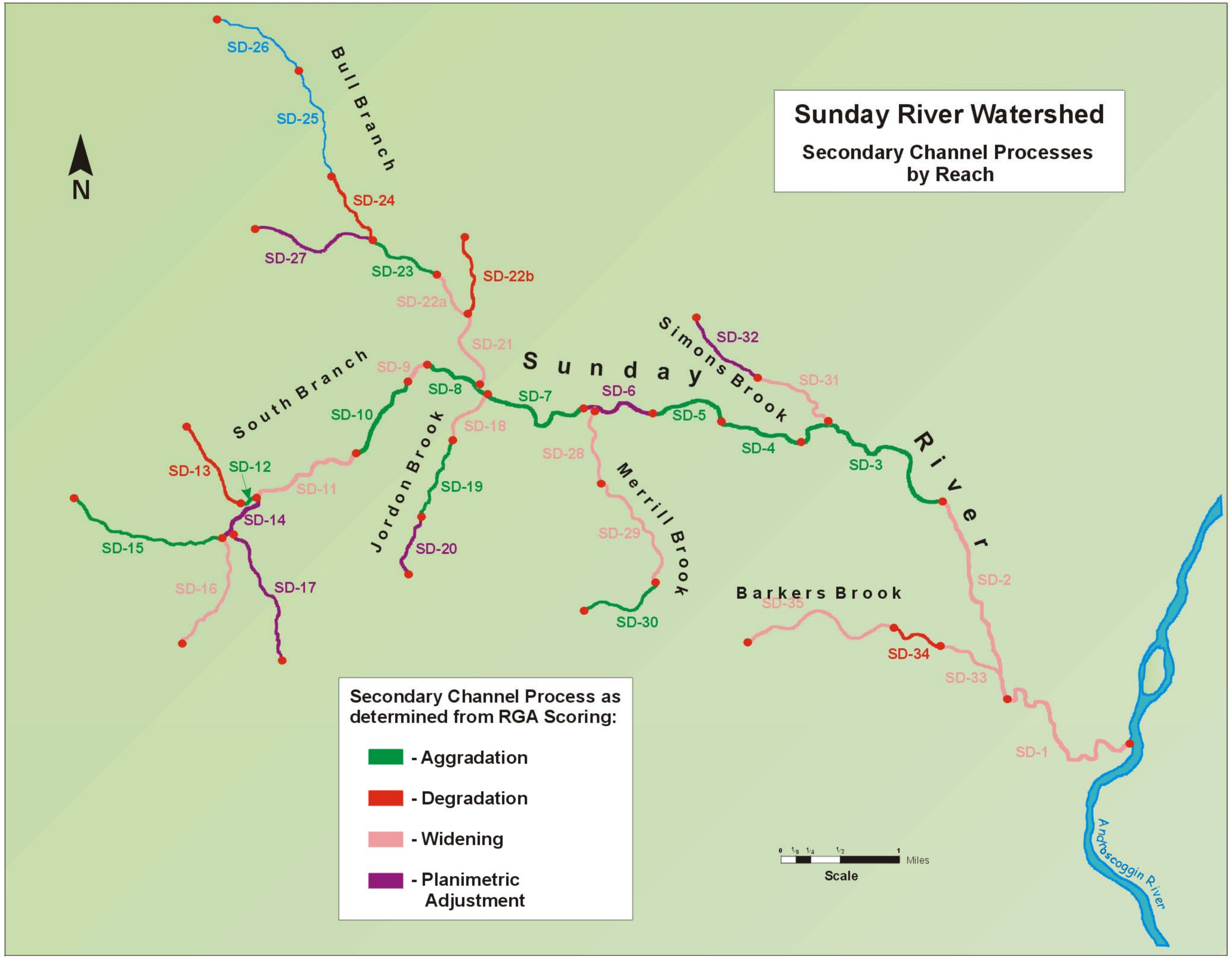


Figure 4.8. Secondary processes as identified by Rapid Geomorphic Assessment.

4.3 Historic Assessment

Historical analyses provided insight into the degree of natural fluvial activity and human impacts, such as channel straightening or changes in land use. For this historic assessment aerial photographs were used both in small format, from 1968 (Scale 1:7920), 1992 (Scale 1:9000), 1999 (Scale 1:9000) and large format, from 1943 (Scale 1:9000), 1968 (Scale 1: 7920) and 1992 (Scale 1:9000). More recent aerial photographs were also reviewed; however, the limited scale of this set made comparison with other series difficult. The assessment documents historical changes in land use and channel planform. Migration rates were not measured due to limited permanent references, forest canopy, scale of aerial photographs and time constraints associated with reviewing the photographs themselves. Nonetheless, some qualitative observations of planform change and an overall picture of land cover and use changes within the watershed on a reach-by-reach scale are provided in **Table 4.4**. The 1943, 1968 and 1992 aerial photographs were used due to their large format. Much of the assessment is qualitative due to inconsistent coverage, time constraints, and scale limitations associated with many of the aerial photograph series.

The observed general trend in land use change has been toward reforestation with a movement away from intensive agriculture. There has also been a substantial increase in riparian cover. Earlier aerial photographs showed substantial activation of channel sediments, with exposed bars, banks and braided sections. As the riparian vegetation re-established itself, many of the bars and channel banks became stabilized and vegetated. Intermittent periods of bar reactivation were also noted; specifically, after 1997 due to large flow events. There were also major channel planform adjustments during these large events. Although much of the sediments may have been stabilized by revegetation there is likely sediment pulses moving through the channel system associated with these periods of excessive sediment supply. It should also be noted that the impact of logging and land clearing in the headwaters would have a cumulative impact on sediment loads in the lower reaches.

Table 4.4. Summary of observations of channel and adjacent lands from historic assessment.

Reach	Land Use		
	1943	1968	1991 – 1992
SD-1	- agriculture with riparian forest - extensive depositional bars evident in upper half of reach - less bars in the lower half of reach - avulsion from 3rd meander bend - evidence of rotational migration of meander bend	- agriculture, with forest taking hold of some farm land - second meander avulsion into old channel extension - sediment bar increases length of reach	- extensive tree cover along channel banks - loss of ~2/3 of agricultural land to forest. - substantial avulsion at third meander with the exposed channel remaining. - further rotation of large bend at end of reach
SD-2	- primarily agriculture along right bank with mostly forest along left bank - one field bottom reach left bank - some riparian trees along fields - extensive bar system along both banks -braided/semi braided around several bends	- only upstream upper reach evident - mostly forested along left bank - mixed agriculture and forest along right bank -several sections with bars bisected with overflow channels - second meander avulsion now low flow channel 198 m long and 40 m wide	- upstream forest - little contact between fields and channel - total loss of meander scar vegetated - avulsion scars third and fourth meanders
SD-3	- both agriculture and forest - extensive depositional bars - semi braided channel - several small islands, both upstream and downstream	- only upper portion of reach available - some bars evident - road crossing present in middle of reach - mainly forested with agriculture on outside of wood land - also some wetland features	- lower portion of reach mainly forest - upper portion of reach predominantly agriculture - numerous bars present in channel - secondary channel also present near upper end of reach - wetland features more extensive then previous air photographs
SD - 4	- forest on both sides of channel with some agricultural fields - low sinuosity	- low sinuosity - continued forest cover - few bends and no bars present	- low sinuosity - continued forest cover - few bends and no bars present
SD – 5	- mostly forested along right bank - mostly wooded riparian zones and agriculture along left bank - see comments for SD-4 about channel relief	- multiple channels splay at downstream meander - several small bars present - continued forest cover	- mainly forested with some logging roads evident - few bars present - one long meander bend
SD-6	- forested - multiple channels with vegetated islands	- continued forest cover - few bars present - multiple channels becoming a single course	- continued forest cover and some logging roads - few bars observed

Reach	Land Use		
	1943	1968	1991 – 1992
SD- 8	- braided channel - well vegetated - exposure along length of reach	- mostly forested - few bars present	- mostly forested - little to no exposed bar material
SD-9	- agricultural fields with some woodlands - braided channel	- mostly forested - few bars present	- mostly forested - exposed bars - evidence of rapid channel realignment, bank deposits 3 to 4 channel widths wide - several channel scars
SD-10	- Both large islands and exposed high flow channels - exposed bed materials - bar deposits are thicker than the active wetted channel - potentially a large course of material	- mostly forested - few bars present	- no exposed materials except on exposed bar - well vegetated
SD-11	N/A		- little exposed material - well vegetated - 2 to 3 vegetated islands or secondary relief channels
SD-12	- vegetated, not exposed		- well vegetated
SD- 13	- vegetated, not exposed		- well vegetated
SD-14			- well vegetated
SD-15	- exposed		- well vegetated, defined meander - gravel extract
SD-16	- vegetated, not exposed		- exposed tributary network - clear cut gravel - some exposed materials - slide
SD-17	- vegetated, not exposed		- vegetated
SD-18	- vegetated, not exposed		- vegetated
SD-19	- vegetated, not exposed		- vegetated
SD-20	- vegetated, not exposed		- vegetated
SD-21	- exposed field in lower 2/3 of reach - forest above multiple channels - active exposed bars almost 100 % of reach		- well vegetated bar deposit - crossing with little exposure except at crossing and below - old avulsion at confluence that was active in 1940

Reach	Land Use		
	1943	**1968**	**1991 – 1992**
SD-22b	- vegetated, some logging - little exposed channel - smaller section of multiple channels		- little or no exposed bar - vegetated
SD-23	- logging interior, mostly on the side - at confluence, material exposed		- little to no exposed bar
SD-24	- vegetated - less exposed bar		- little or no exposed bar - vegetated
SD-25	- vegetated, well defined channel - some exposed bars		- little or no exposed bar - vegetated
SD-26	- vegetated, well defined channel - some exposed bars		- little or no exposed bar - vegetated
SD-27	- well vegetated	- less exposed bar	- little or no exposed bar - vegetated
SD-28	- vegetated		- well defined valley - well vegetated - no exposed channel evident
SD-29	- areas of clear cutting within basin		- well defined valley - well vegetated - no exposed channel evident
SD-30			- ski hill upper part of basin - cannot delineate channel
SD-31	- fully forested - channel not observable	- fully forested - channel not observable	- fully forested
SD-32	- fully forested - channel not observable	- fully forested - channel not observable	- fully forested
SD-33	- farmland, some riparian trees near confluence - road crossing	- farmland some riparian cover near confluence	- forested from confluence to bridge - one field on left bank exposed
SD-34	- forest cover - some farming within basin - exposed bars	- forest cover, some farming - channel hard to discern	- forest cover - additional crossings - channel hard to discern
SD-35	- forest cover - channel hard to discern	- forest cover - expansion of the ski resort	- expanded ski facilities - new crossings - forested

4.4 Detailed Sites

The locations of the detailed sites were determined on the basis of their relative sensitivity (according to the RGA, RSAT and HABSCORE measures), spatial coverage of the watershed (main tributaries and the main branch) and potential for use as reference reaches (i.e., reaches potentially used during development of restoration plans). **Figure 4.9** identifies the detailed field assessment locations and monitoring sites (discussed in the next section).

Detailed geomorphic assessments for this study included measurements of channel and bank characteristics and bankfull flow conditions. At each of the detailed sites, cross-sections were measured at five to ten locations, including pools, riffles and transitional areas. At each cross-section, bankfull width and depth, entrenchment, as well as low flow dimensions were recorded. Substrate was sampled using a modified Wolman pebble count. Sub-pavement was also characterized at each cross-section. Bank assessment included measurements of height, angle, bank composition, *in-situ* shear strength, vegetation and rooting depth. These cross-sections were placed over a minimum of two meander wavelengths. A level survey of the site extending upstream and downstream of the cross-section locations was also conducted. The survey included bankfull elevations, maximum pool depth, top and bottom of riffles and any obstruction to flow and provided measures of energy gradient, inter-pool gradient and riffle gradient. **Appendix B** provides a summary of measurements from the detailed sites.

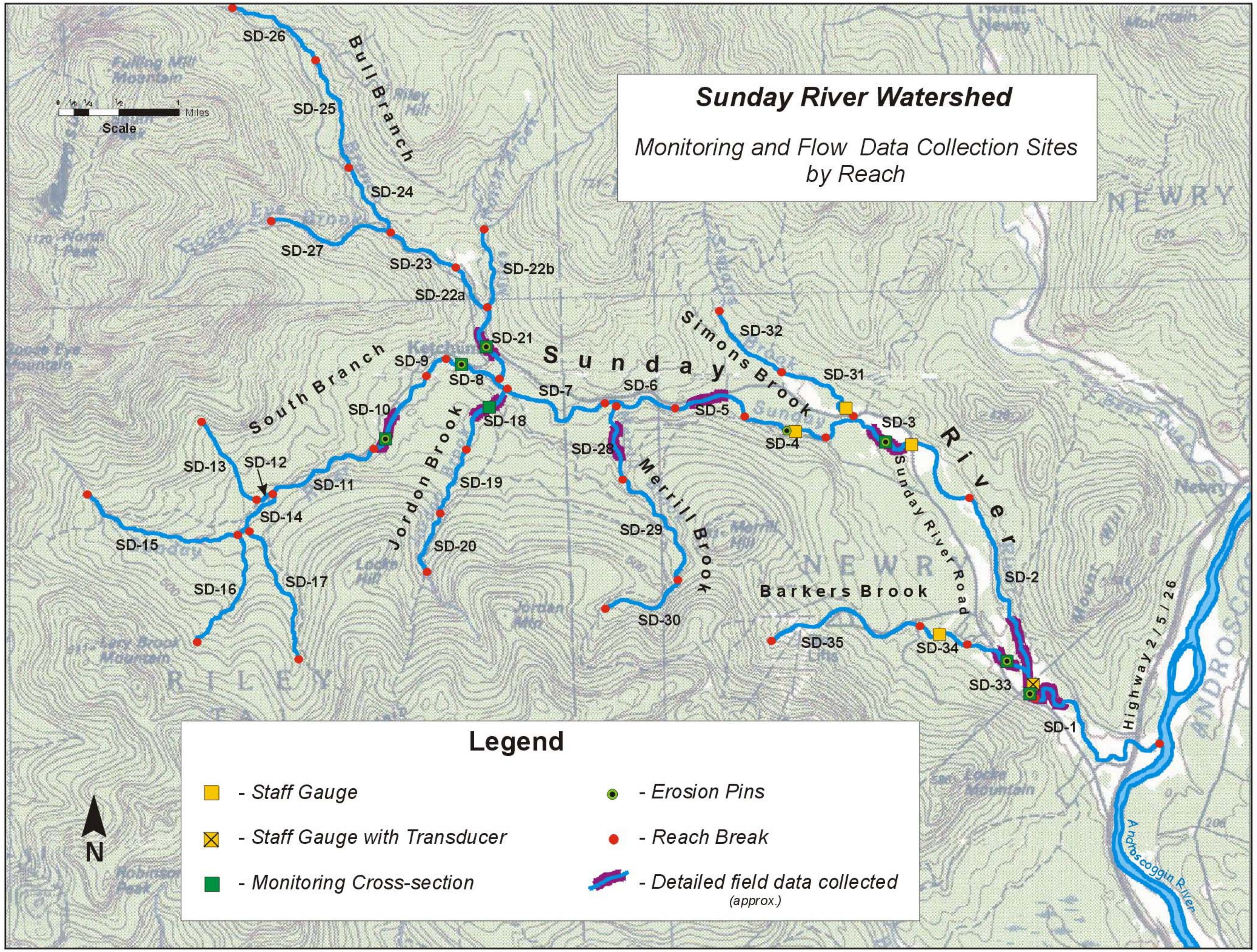


Figure 4.9. Detailed field assessment locations and monitoring sites (discussed in the next section).

Table 4.5 and **4.6** provide an at-a-glance summary of the bankfull characteristics and erosion thresholds for all the detailed sites. The bankfull characteristics and process observations from each detailed site are also provided to set the context for the thresholds. The collection of detailed field information allows for analyses to be performed based on critical shear stress and permissible velocities in order to identify erosion thresholds. Erosion thresholds determine the magnitude of flows required to potentially erode and transport sediment. When compared to bankfull conditions they provide an indication of channel stability. Values from **Table 4.5** and **4.6** can also be used to guide selection of stable bed and bank materials for restoration purposes. Streams continually adjust their dimensions to accommodate changes in their sediment transport and discharge regimes. As such, thresholds of particle movement and transport will vary spatially and temporally as watercourses adjust to local variations in slope, bed material, discharge and modifying factors. The calculations performed to determine critical discharge for bed materials were based on formulas for critical shear stress (Shields, modified by Miller et al., 1977) and permissible velocity (Komar, 1987). These methods are well suited for the coarse sediment channels found within the watershed. The erosion thresholds were based on the threshold for the D_{50} (median grain size), which is the general practice. Several clarifications are required with respect to the tables. The cross-sections collected in the field were simplified to allow discharge to be readily back calculated. First, it should be noted that the critical depth calculated by the models is, more specifically, a maximum critical depth of the defined trapezoid. Consequently, in some cases the critical depth of a site is greater than the average bankfull depth. In most cases the maximum bankfull depth would still prove larger than the maximum critical depth. If, in fact, the discharge values calculated by the models exceed bankfull discharge, the models assume that these flows are contained within the general geometry of the bankfull cross section and do not account for the geometry of the floodplain. In these cases, the discharge value provided may be taken as a minimum potential discharge. The Manning's 'n' values provided in the tables were for bankfull conditions and were derived from Limerinos' (1970) equation using average bankfull depth and the D_{84} for a site. Note that the stream type characterizations presented in **Table 4.5** and **4.6** are based on the Level II stream classification by Rosgen (1996), which, in addition to sinuosity, gradient and entrenchment, accounts for channel bed materials.

A comparison of bankfull tractive force to the critical shear stress indicates that in the lower reaches, only near bankfull conditions is the median materials potentially entrained. Upstream the median materials are entrained below bankfull, and in the steeper tributary reaches most of the bed material can be potentially mobilized under bankfull flow conditions, which is illustrated by comparing the bankfull tractive forces to the amount of critical shear stress required to move the D_{84} sediment sizes.

Table 4.5. Bankfull and threshold conditions.

Parameter	SD-1	SD-2	SD-3	SD-5	SD-10
Average Bankfull Width (ft)	75.83	94.82	126.12	117.95	48.05
Average Bankfull Depth (ft)	2.89	2.62	1.84	2.56	2.20
Bankfull Gradient (%)	0.085	0.085	0.44	0.70	2.38
Bed Material D_{50} (ft)	0.09	0.10	0.14	0.14	0.15
Bed Material D_{84} (ft)	0.17	0.20	0.32	0.32	0.52
Bedrock Exposure/Control	No	No	No	No	No
Bank Materials	Silt/vfs	Cs/fs/vfs/silt	Cob/p/vcs/cs	Fs	Boulders/sand
Manning's n at Bankfull*	0.032	0.032	0.042	0.037	0.044
Average Bankfull Velocity (fts^{-1})	2.89	2.57	3.55	5.20	3.54
Average Bankfull Discharge (ft^3s^{-1})	633.19	640.22	823.89	1791.88	661.45
Flow competence ($ft\ s^{-1}$) @ D_{50}	3.01	3.16	3.82	3.68	3.80
Flow competence ($ft\ s^{-1}$) @ D_{84}	3.94	4.29	5.96	5.35	6.67
Tractive Force at Bankfull ($lbs\ ft^{-2}$)	0.15	0.14	0.50	0.41	0.25
Critical Shear ($lbs\ ft^{-2}$) @ D_{50}	0.43	0.47	0.72	0.66	0.71
Critical Shear ($lbs\ ft^{-2}$) @ D_{84}	0.77	0.93	1.89	1.50	2.42
Critical Discharge ($ft^3\ s^{-1}$)	378.22	944.64	557.22	374.76	521.77
Critical Depth (ft)	3.05	3.44	2.00	2.95	3.18
Critical Velocity ($ft\ s^{-1}$)	3.02	3.15	3.84	3.67	3.80
Stream Type	E4	F4	C3	G4c	B3
Site Description	- large deposit on left bank, sandy substrate, major woody debris in channel, island formation in channel, good riffle pool sequencing	- deposition along both banks through out reach, major woody debris in channel, both banks eroded in some parts, good riffle pool sequencing	- large point bar upstream of bridge, woody debris in channel, aggradation on banks, leaning trees, good riffle pool sequencing, island formation in downstream section	- both banks are low lying, both banks have point bars throughout reach, major undercut along the left bank	- good riparian cover, washed out road near right bank, both banks are eroded with exposed tree roots, secondary channel along left bank

* Manning's 'n' based on Limerinos (1970)

Table 4.6. Bankfull and threshold conditions.

Parameter	SD-18	SD-21	SD-28	SD-33
Average Bankfull Width (ft)	28.63	48.05	39.10	26.86
Average Bankfull Depth (ft)	1.71	2.20	1.71	1.74
Bankfull Gradient (%)	5.42	1.44	6.17	0.19
Bed Material D_{50} (ft)	0.23	0.37	0.26	0.07
Bed Material D_{84} (ft)	0.68	0.82	0.66	0.17
Bedrock Exposure/Control	Yes	No	No	No
Bank Materials	NA	Sand/roots	Boul/cob/sand /grav/org	Ms/silt
Manning's n at Bankfull*	0.053	0.052	0.056	0.032
Average Bankfull Velocity (ft s^{-1})	7.26	10.81	14.66	2.99
Average Bankfull Discharge (ft^3 s^{-1})	596.82	1490.29	1057.68	104.57
Flow competence (ft s^{-1}) @ D_{50}	4.60	5.70	4.83	2.73
Flow competence (ft s^{-1}) @ D_{84}	7.53	8.21	7.42	3.93
Tractive Force at Bankfull (lbs ft^{-2})	1.21	2.47	15.17	0.12
Critical Shear (lbs ft^{-2}) @ D_{50}	1.08	1.72	1.20	0.35
Critical Shear (lbs ft^{-2}) @ D_{84}	3.15	3.80	3.05	0.77
Critical Discharge (ft^3 s^{-1})	58.86	438.13	93.34	78.61
Critical Depth (ft)	0.85	2.16	0.82	1.57
Critical Velocity (ft s^{-1})	4.59	5.71	4.82	2.72
Stream Type	B3a	B3c	A3	C4c
Site Description	- channel had exposed bedrock in the lower part of reach, many large boulders in channel, undercutting along both banks, valley wall contact	- channel had good riffle pool sequencing, island formation near mid-reach, high flow channel along left bank, deposition along left bank	- right bank is steep and undercut, large boulders in channel, mid channel bar present	- large point bar deposit along left bank with fresh sand deposits, several high flow channels present, channel substrate soft and unconsolidated, many fallen trees and woody debris on banks

* Manning's 'n' based on Limerinos (1970)

4.5 Erosion Monitoring

In addition to collecting data of existing conditions, erosion pins and control cross-sections were installed throughout the watershed that enable an evaluation of rates of channel change (e.g., bank erosion, bed scour and fill). Typically, two to four erosion pins were installed at varying locations along banks at each field site. The pins have been revisited once since installation, this followed several flow events. The pins were placed both in channel bends (where bank erosion was expected to occur) and in straight sections that are usually more stable. Installation occurred between June 3, 2003 and June 5, 2003. The sites were revisited August 19, 2003 and August 20, 2003. Erosion pin locations are presented graphically in **Figure 4.9**, while bank erosion rates to date are provided in **Appendix C**.

Repeated surveys were conducted at eight monitoring cross-sections to document processes of deposition, downcutting and channel widening. Cross-sections were generally located in the vicinity of erosion pins in order to provide comparison data. Generally, these sections were located on riffles as they are the most stable and persistent channel features. Control cross-section locations are marked on **Figure 4.9**. Initial set-up of the control cross-sections occurred between June 3, 2003 and June 5, 2003. Re-measuring of the sections was completed between August 19, 2003 and August 20. Qualitative changes in cross-sectional form over the period of measurement can be assessed from the graphs in **Appendix C**. Results from six of the eight locations are presented in the Appendix; as proper control sections at two locations (SD-18 & SD-21) were not established. In regard to the monitoring site at SD-10; the cross-section was installed June 6, 2000, by the Maine Department of Inland Fisheries and Wildlife, and there was little change noted in the channel form since this previous survey (**Appendix C**).

Results of monitoring to date indicate that there has been only minimal change in cross-sectional shape and area. Most control sections display only minor adjustments which are likely due to a shift or movement of large particles during the recent high flow events which occurred during the period of monitoring. These results indicate that although several seasonally significant flow events (although all well below two year returns) have occurred during the monitoring period, the channel at these locations has remained stable. Erosion pin results indicate a fairly low degree of channel migration during this period. With the exception of the left bank pin installed upstream of the covered bridge (-6ft/yr), most erosion rates measured are typical for a dynamic system such as the Sunday River and the average result was close to negligible (<0.02ft/yr). This average value accounted for sites experiencing either erosion or deposition/in-filling and omitted the exceptional value that was recorded at the erosion pin upstream of the covered bridge, whereby results ranged as high as 0.429 ft/yr of erosion to as low as 0.593 ft/yr of deposition. The erosion pin results however do not provide a robust estimate of long term trends due to the limited period of monitoring to date. It is recommended that monitoring be continued to better clarify trends of erosion and deposition observed to date.

A brief protocol is provided below to help in standardizing future monitoring by volunteers. At each site one cross-section would be established as a control cross-section. This section was typically situated in the middle of the site and on a riffle. At these sections, a pin (usually 12 inch nails in a washer painted orange) was embedded on the top of each bank. These pins remain in place so that a tape can easily and accurately be tied to the pins so that the cross-section can re-measured in the future. Flagging tape and spray paint marks on trees were placed in the vicinity of the monitoring cross-section to aid in future recognition of the site location. Once a tape has been extended across the creek between the control pins, measurements should be taken from the tape to the bed. Water level should also be recorded. Measurements should be conducted from left to right looking downstream. Distance between measurements should be less than 5 percent of the cross-section width. Always make sure the height of the tape to the base of the pin is measured on both sides. Erosion pins were installed near the control cross-section in most cases. When revisiting erosion pins, the amount of bar left exposed should be recorded (from the pin to the creek bank). If a substantial amount of the pin is exposed, it should be hammered into the bank and the reset pin length should be recorded. Description of the pin location with respect to bank height, left or right channel bank, and relative distance to cross-sections and other erosion pins should be recorded. Photographs of each pin should also be taken.

4.6 Fisheries

The fish community in the Sunday River is maintained entirely through natural reproduction. The adjacent segment of the Androscoggin River is a transition area between a predominantly coldwater fish assemblage between Errol, New Hampshire and West Bethel, Maine, and the predominantly warmwater fish assemblage further downstream. As a result, the Androscoggin in this reach contains both warmwater and coldwater species. Tributaries in this reach of the Androscoggin typically provide refuge and nursery habitat for cold water salmonid species such as brook, rainbow and brown trout (Kleinschmidt Associates 1988, Kleinschmidt Associates 1999), and the Sunday River contains populations of such fish as well.

The Maine Department of Inland Fisheries and Wildlife (MDIFW) conducted a detailed biological survey in the Sunday River in 1998 (Bonney, *et al.*, 1999). A prior, more cursory, survey was performed by MDIFW in 1963, and some limited fish sampling was conducted in 1975. The 1998 survey included an assessment of available habitat, summer condition water quality, and the distribution and relative abundance of fish species.

Water Quality

Overall, water quality appears suitable to support a native coldwater fish community, based on the data in Bonney *et al.* (1999). Thermal stress is a potential coldwater habitat and macrohabitat concern in most small Maine brooks during summer months as brook trout, a native salmonid, require cold, well-oxygenated waters less than approximately 70^{o}F (Scott and Crossman, 1973). Small and slow flowing streams are often subjected to solar warming if overhead cover is poor, and/or groundwater inflows are limited. The 1998 survey included both long-term (May-September) water temperature monitoring at two reference sites, as well as instantaneous measurements taken concurrently with fish sampling. The long term data show that August had the warmest ambient temperatures, with average and maximum temperatures well within the suitable range for brook trout preferred thermal requirements in the upper sites. The middle site generally also maintained brook trout suitable average temperatures, but indicated at least one excursion to 75 ^{o}F, which could potentially stress brook trout if the duration was sufficient and no local refugia were available. However, such a temperature would be within the tolerances of brown and rainbow trout. Instantaneous temperature data collection indicate water temperatures suitable for brook trout.

Habitat

Generally, adult and juvenile brook trout prefer unembedded gravel, cobble and boulder substrates with abundant instream object cover and/or canopy or bankside overhead and rootwad cover. Tree canopy enhances brook trout habitat by providing shelter from predators, retarding solar warming, and contributing woody debris and insect forage recruitment. Spawning and incubation habitat is comprised of unimbedded, stable gravel bars that adult fish can dig redds (nests) to bury eggs in. Flows must be sufficient to submerge the redds in order to avoid ice damage formation and provide circulation through the gravels. The eggs incubate in the gravel during the fall and winter months, and require unimbedded interstitial spaces to promote water circulation and aeration.

Bonney *et al.* (1999) ranked habitat suitability using Habitat Suitability Index (HSI) criteria for adult, juvenile and juvenile-edge habitat, based on a 24-reach stream basin segmentation scheme. The HSI scores habitat quality between 1.0 and 0.0, with 1 being optimal and 0 indicating no suitability for the species and lifestages. The score results from rating the combined quality of depth, velocity, substrate and cover available at each assessment point.

The quantity and quality of habitat varied extensively among stream reaches; **Table 4.7** summarizes brook trout habitat quality for all 24 of the combined reaches. There was approximately twice as much adult habitat as there was juvenile habitat, and overall, the suitability of the adult habitat was better than then that for juvenile brook trout.

Approximately 31% of the adult habitat was scored as 0.7, which for purposes of this assessment can be considered as "fair" habitat; another 33% of adult habitat scored 0.5-0.6 which can be characterized as "poor"; and finally, 24% of adult habitat scored 0.8-0.9 which could be considered "good". No habitat was rated as "optimal". By contrast, 57% of the juvenile habitat scored as "poor", 42% as "fair", and 11% as "good," with again, no habitat rated optimal. Juvenile edge habitat was similar: 58% "poor", 30% "fair" and 12% "good" with none rated optimal.

Table 4.7. Summary of brook trout habitat quality in 24 reaches of the Sunday River (Bonney, *et al.* 1999).

ADULT

HSI rank	Area (ft^2)	Percentage
0.3	49029	2%
0.4	314856	10%
0.5	489665	16%
0.6	518895	17%
0.7	959466	31%
0.8	536906	17%
0.9	207985	7%

JUVENILE

HSI rank	Area (ft^2)	Percentage
0.3	104882	8%
0.4	101120	8%
0.5	364270	29%
0.6	351491	28%
0.7	175007	14%
0.8	99405	8%
0.9	40480	3%

JUVENILE (edge)

HSI rank	Area (ft^2)	Percentage
0.3	32843	7%
0.4	11522	3%
0.5	185764	42%
0.6	72184	16%
0.7	86242	20%
0.8	43050	10%
0.9	8478	2%

5.0 BASIN HYDROLOGY

5.1 Sunday River Watershed Description

The Sunday River, a tributary of the Androscoggin River, has a drainage area of approximately 51.4 square miles at its mouth. Major tributaries of the Sunday River include the South Branch of the Sunday River (1.7 square miles), the Bull Branch (7.5 square miles), Jordan Brook (2.3 square miles), Merrill Brook (2.3 square miles), Eames Brook (0.4 square miles) , Simons Brook (3.9 square miles) and Barkers Brook (3.4 square miles). The total drainage area of these tributary subbasins is approximately 21.5 square miles, or 42% of the Sunday River watershed.

As reported in the "Biological Summary of the Sunday River" (1999), the "river drops in elevation from 2,840 feet at its origin to 625 at the Androscoggin River in Bethel, for a total of 2,215 feet or 159.5 feet per mile and an average slope of 3.9%". In the upper watershed the Sunday River is steeper than 3.9%, with its tributaries demonstrating slopes between 8% and 15%. The Sunday River is approximately 13.3 miles long from the origin of its headwaters in the mountains to the confluence with the Androscoggin River. The lower Sunday River, downstream of the confluence of Simons Brook, is characterized by a wider valley and floodplain, gentler slopes and a more meandering channel.

The steep, hilly watershed of the Sunday River is primarily forested with spruce, fir and mixed hardwoods. In the higher elevations some forest cover has been displaced by roads, logging, downhill ski trails, a golf course, and building construction. The lower watershed has historically had a lot of agricultural land use, and includes open areas such as fields and pastures. The imperviousness area of the lower watershed is probably increasing as more buildings, roads, parking lots and driveways are being constructed.

According to the National Wetlands Inventory, less than 1% of the Sunday River watershed is classified as wetland, which includes lacustrine, riverine and palustrine wetland. The largest water body in the basin, Speck Pond (9 acres), lies in the mountainous headwaters of the Bull Branch, and does not provide any meaningful flood storage in the watershed. Most of the basin wetlands (230+ acres) are located in the lower part of the watershed within the floodplain of the Sunday River and are classified as riverine wetlands.

Watershed soils are predominantly glacial till, glacial outwash and alluvium, with a small amount of organic soils. Exposed bedrock exists in many places in the upper watershed.

5.2 Hydroclimatology

Due to the steeply sloping watershed, steeply sloping tributaries and a small percentage of wetlands in the entire basin, the river is very "flashy" and responds quickly to rainfall and snowmelt events with sharply peaked hydrographs. Intense precipitation events, such as those associated with summer thunderstorms or autumnal tropical storms have been known to cause high flows in the Sunday River.

The Sunday River has never been gaged, but a nearby U.S. Geological Survey streamgage on the Wild River near Gilead, Maine (USGS Gage No. 01054200) is thought to be representative of the hydrology of both western Maine Rivers. The Wild River basin represented by the streamgage is 69.5 square miles (versus 51.4 square miles for the Sunday River). The slope of the Wild River and Sunday River are 104.6 feet per mile and 159.5 feet per mile, respectively. The percent wetlands are nearly 0.7% for the Wild River and nearly 0.9% for the Sunday River. The upper elevations in the watersheds are approximately 2,360 feet (Wild River) and 2,840 feet (Sunday River). Compared to other Maine rivers, the Wild and Sunday Rivers are much steeper, have headwaters at higher elevations, and have much fewer wetlands in their basins, including lakes and ponds.

The Wild River streamgage has a record that extends back to July 1964. **Table 5.1** (see **Appendix D**) is a listing of annual peak flows for the Wild River for each "water year" (October through September the following year). Peak flows that occurred in January, February, March, April, early May, late November and December are the most likely to be associated with snowmelt, and occurred for 26 (approximately two-thirds) of the 39 listed records. However, for 13 water years, or approximately one-third of the record, annual peak flows occurred during events that were probably associated with hurricanes or tropical depressions, which tend to have intense precipitation of short duration but no snowfall. A significant number of high flows occurred in October, which is near the end of hurricane season. Note that the four highest annual peak flows gaged or surveyed for the Wild River—October 24, 1959 (28,300 cfs), October 22, 1995 (24,500 cfs), June 14, 1998 (19,200 cfs) and September 17, 1999 (18,100 cfs)—were not spring snowmelt events, and were probably associated with tropical storms or intense summer thunderstorms. Therefore, it is more appropriate to say that although flooding in western Maine rivers is principally caused by snowmelt events, especially in midwinter or early spring, intense summer storms or late season tropical storms can also cause flooding, with peak flows resembling or greater than floods associated with snowmelt.

During the Sunday River watershed survey work in 2003, a number of references were made to a high flow event that occurred in October several years ago. The flooding in the Sunday River associated with that event was believed to have caused some changes in the river, especially the movement and deposition of large volumes of sediment. Although it was originally assumed that this was the same October 1996 event that saw over 18 inches of rain fall in parts of southern Maine, an event in October 1995 may have been even more significant for the Sunday River. According to the Wild River streamgage, a peak flow of 24,500 cfs occurred on October 22, 1995. Nearly a year later (October 21, 1996), the peak flow was only 8,750 cfs. A USGS report for the October 1996 event (1997) confirmed that the extreme amounts of precipitation were localized in southern Maine, and diminished northward. Therefore, it is believed that the October 1995 storm, not the October 1996 storm, was more likely to have caused the high flow in the Sunday River that many people thought had resulted in some river adjustment. While tropical depression Opal occurred early in October 1995 and would not have directly caused the peak in the Wild River, this event led off one of the wettest Octobers of record in the Northeast and could have resulted in saturated soil conditions and higher than normal river flows that led to high peak flows later in the month. It is likely that the Sunday River had a similar response to the October 1995 conditions as the Wild River.

5.3 Sunday River Watershed Flow Frequencies

Since the Sunday River and its tributaries are not gaged, flow frequency data for the watershed must be calculated using prorated streamgage data. As discussed earlier, the Wild River streamgage has a long term record and a contributing watershed that closely resembles the Sunday River basin in slope, elevation, land cover, soils, drainage area and geographical area, more so than other gaged watersheds in the region.

Gaged flows were prorated from the Wild River streamgage to the Sunday River using a straight drainage area proration:

$Q_{\text{Sunday River}} = Q_{\text{Wild River}} \times (\text{Drainage Area}_{\text{Wild River}} / \text{Drainage Area}_{\text{Sunday River}})$

Figures 5.1 through **5.13** (see **APPENDIX D**) illustrate the prorated annual and monthly flow duration curves for many locations along the Sunday River and Bull Branch. Proration to tributaries was not performed, since their basin areas are much smaller than the drainage area for the Wild River streamgage. The flow duration curves are probably most reliable for the lower Sunday River, with a greater uncertainty as the drainage area gets farther away from the drainage area of the Wild River (69.5 square miles).

Since floods greatly influence riverine morphology, an understanding of flood magnitude is usually helpful for restoration planning. For ungaged watersheds in Maine, the USGS often uses regression equations to determine peak flows for floods of selected recurrence intervals. As described in "Estimating the Magnitude of Peak Flows for Streams in Maine for Selected Recurrence Intervals"

(1999), the percentage of basin wetlands and basin area can be used to calculate peak flows for the 2-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year floods. Estimates using these equations have an "average standard error of prediction" that can vary between +53.5% and -34.8%, depending on the recurrence interval. Although this is a fairly wide range, the regression equations are widely used in ungaged watersheds to estimate peak flood flows, delineate floodplains and even design infrastructure such as culverts and bridges.

In the Town of Newry Flood Insurance Study (2003), the USGS used regression equations to calculate the 100-year discharge for the Sunday River and Barkers Brook. At the Newry/Bethel town line, where the drainage area of the Sunday River is 50.0 square miles, the USGS calculated a 100-year flow of 7,270 cfs. For Barkers Brook at its confluence with the Sunday River (a drainage area of 3.38 square miles), the USGS estimated a 100-year flow of 1,035 cfs.

The 100-year peak flow calculated for the Sunday River (7,270 cfs) immediately raises some concerns. Given that the Wild River--with a slightly larger drainage area--had annual peak flows of 24,500 cfs, 8,750 cfs, 19,200 cfs, 18,100 cfs, 11,200 cfs, 8,060 cfs and 9,250 cfs in the last seven years, the 100-year flow of 7,270 cfs for the Sunday River seems low. Even though the Wild River streamgage data were used to develop the USGS's regression equations, both the Wild River and Sunday River have watersheds that are steeper, at higher elevations and with less wetlands than most rivers in Maine. Given that the regression equations do not include slope as a variable, the equations may not be representative of flows in mountainous western Maine watersheds. The USGS report (1999) even hints at this phenomenon noting that although the 100-year flow for the Wild River is approximately 27,600 cfs from streamgage data, the regression equations calculate a 100-year flow of approximately 10,300 cfs, 63% lower than the gage data.

Table 5.2 (see **APPENDIX D**) compares flood flows calculated using the USGS regression equations with flood flows prorated from the Wild River streamgage. For the prorated flows, peak flood flows for the Sunday River were calculated by multiplying the peak flow on the Wild River by the straight ratio of drainage areas.

Using the Wild River gage data, the 100-year peak flow at the Newry/Bethel town line (50.0 square mile drainage area) would be 19,850 cfs, which is obviously much greater than the 7,270 cfs flow used in the Flood Insurance Study (2003). This difference is very significant, since the 7,270 cfs is the basis for not only the delineation of the 100-year floodplain, but is also used to regulate development in the floodplain. The 7,270 cfs may be less than a 5-year flood, meaning that most of the 100-year floodplain may not have been identified on the floodplain mapping. There is also an obvious concern about the regression equations being used to estimate design flows for culverts and bridges; in the lower Sunday River, these structures may end up undersized. *Therefore, it is recommended that the peak flood flows estimated from the Wild River streamgage be used for restoration design.*

There is more uncertainty prorating Wild River flows to Barkers Brook, due to the large difference in drainage areas. However, a small, steep watershed like Barkers Brook should have peak flows that are at least as great in cfsm (cfs per square mile of watershed area) as for the Wild River, meaning that the 100-year flood flow for Barkers Brook should probably be at least 1,340 cfs, 30% greater than the peak flow of 1,035 cfs listed in the Flood Insurance Study. Again, caution should be used if flow estimates from the regression equations are used for restoration design, flow conveyance design or floodplain regulation in the Sunday River watershed.

5.4 Hydrologic Monitoring During Watershed Assessment

In order to further understand the hydrology of the Sunday River watershed, flow and stage data was collected during the summer 2003 field season. The data includes recorded data from water level loggers as well as instantaneous staff gage readings.

The following describes the hydrologic data collection in the watershed.

Bull Branch Upstream of Twin Bridges

With the assistance of Kleinschmidt, the Maine DOT installed a recording water level transducer on the Bull Branch upstream of the twin bridges. The gage recorded continuously between June 27, 2003 and August 1, 2003, at which time the transducer was either washed away during a high flow event or vandalized.

The following flows were gaged on the Bull Branch by either Kleinschmidt or the Maine DOT in the summer of 2003.

Date	Time	Gaged Flow (cfs)
June 3, 2003	3:35 p.m. – 4:00 p.m.	22
June 23, 2003	10:30 a.m. – 10:53 a.m.	15
July 2, 2003	unknown	5
July 11, 2003	~ 11:00 a.m.	16
July 24, 2003	~ 2:00 p.m.	8
August 16, 2003	~ 11:00 a.m.	59
August 20, 2003	11:58 a.m. – 12:20 p.m.+	17

The recording transducer measured down to the water level from a reference point. For the period of record, the minimum reading was -30.7" (July 20-21) and the maximum reading was -14.4" (July 24), a range of 16.3".

A stage-discharge relationship was developed for the transducer from three gaged flows.

The transducer captured two significant flow events in Bull Branch, on July 11th and July 24th. For the July 11th event, volunteer monitors noted between 1.1" and 1.3" of rain elsewhere in the Sunday River watershed. **Figure 5.14** plots the hydrograph for Bull Branch. The water level in Bull Branch rose 13.4" (from approximately 2 cfs to 46 cfs) in 10.5 hours, peaking at approximately 3 p.m. on July 11th.

Volunteer monitors elsewhere in the Sunday River watershed noted rainfall of approximately 1" on July 23 and 24, as well as smaller amounts of rainfall a few days earlier. The Bull Branch responded to the event as shown in **Figure 5.15**. For the second peak, the water level in Bull Branch rose 13.4" (from approximately 10 cfs to 54 cfs) in 4.0 hours, peaking at approximately 10:30 p.m. on July 24th.

Note that the peak flows for both events were higher than gaged flows used to prepare the stage-discharge relationship, lending the high flows some uncertainty.

Merrill Brook Upstream of Culvert

With the assistance of Kleinschmidt, the Maine DOT installed a recording water level transducer on Merrill Brook upstream of the large culvert underneath the Monkey Brook Road.

In the summer of 2003, the transducer recorded continuously between June 27 and August 1, between August 5 and August 16, and between August 26 and September 5, at which time it was intentionally removed.

The following flows were gaged on Merrill Brook by either Kleinschmidt or the Maine DOT in the summer of 2003.

Date	**Time**	**Gaged Flow (cfs)**
June 23, 2003	12:17 p.m. – 12:28 p.m.	1.6
July 2, 2003	unknown	0.1 (first gage), 0.2 (second gage)
July 11, 2003	~ 12:00 p.m.	2.4
July 24, 2003	~ 3:00 p.m.	0.3
August 16, 2003	~ 10:00 a.m.	1.8
August 20, 2003	9:50 a.m. – 10:14 a.m.	0.6

The recording transducer measured down to the water level from a reference point. For the period of record, the minimum reading was -16.9" (July 10-11) and the maximum reading was +1.1" (August 10), a range of 18.0".

The gage captured the hydrographs of three significant flow events, on July 11, August 6th and August 10th. Using gaged flow data, a stage-discharge relationship was developed to convert water levels to streamflow for each event.

For the July 11th event, volunteer monitors noted between 1.1" and 1.3" of rain elsewhere in the Sunday River watershed. **Figure 5.16** plots the hydrograph for Merrill Brook. The water level in Merrill Brook rose 5.6" (from less than 0.1 cfs to 2.5 cfs) in 5 hours, peaking at approximately 1:00 p.m. on July 11th.

Although volunteer monitors elsewhere in the Sunday River watershed noted rainfall of approximately 1" on July 23 and 24, as well as smaller amounts of rainfall a few days before, Merrill Brook did not respond dramatically to that event, rising less than 2". This indicates that precipitation may have been very localized in the Sunday River watershed, which is not unusual for midsummer thunderstorms.

In August, significant rainfall events a few days apart created a double-peaked hydrograph in Merrill Brook and many other parts of the Sunday River watershed. The volunteer monitor for Simons Brook noted rainfall of 2.8" on August 6 th and 2.7" of rainfall on August 9th. Another monitor elsewhere in the Sunday River watershed noted "at least" 1.5" of rain on August 6th, 1.75" of rain on or before August 10th, and a reading of 3.75" by August 11th, which may have included some or all of the previously reported rainfall. **Figure 5.17** illustrates the response of Merrill Brook to this event. (Note that records are not available between August 1 and August 5.) The flat peaks indicate that the transducer was probably overtopped during the two August events, and that the peak flows were actually higher than 7.5 cfs. (Note that the peak flow is also much greater than the range of gaged flows used to prepare the stage-discharge relationship for the gage, which would also tend to underestimate flow.) However, the hydrograph does illustrate the steep rising limb of both hydrographs, illustrating the flashy response to rainfall. On August 10th, Merrill Brook rose 11.1" in only 3.5 hours.

Sunday River Below Confluence With Jordan Brook

A staff gage constructed with a ruler was observed by a volunteer monitor between June 10, 2003 and August 3, 2003. A total of 19 readings were reported by the volunteer, with the staff gage being reset after a rainstorm on June 12th. Staff gage readings varied from a minimum of 1.75" (July 8) to a maximum of 7" (July 25) for the period between June 23 and August 3. Weather and recent rainfall was noted for each entry. No stage-discharge calibration was made for the staff gage.

Simons Brook near Fleet Property

Although a staff gage (ruler set on rebar) was initially set by Kleinschmidt near the Sunday River road, this gage was subsequently moved by the volunteer monitor to a site just upstream. Although measurements had been made to calculate a stage-discharge relationship for the staff gage in its original location, the relationship was invalidated when the staff gage was moved.

Nevertheless, the staff gage on Simons Brook provided valuable information. The staff gage represented the longest monitoring period for any gage in the watershed, a total of 86 instantaneous observations between June 6, 2003 and November 13, 2003. Weather and recent rainfall were also noted. For the period of record, the staff gage readings varied between a minimum of 0" (the brook was noted as being "dry" for multi-day periods in late June, July, August and early September) and a maximum of 24" (August 9). Several increases in stage of more than 10" in 24 hours were noted in the record, indicating that Simons Brook is very responsive to significant rainfall.

Sunday River at Herlihy Site

A staff gage constructed with a ruler was observed by a volunteer monitor between June 8, 2003 and August 7, 2003, at which time the staff gage was washed away by high flows. A total of 43 readings were reported by the volunteer. Staff gage readings varied from a minimum of 1" (July 6) to a maximum of 23" (July 28) for the period of record. Weather and recent rainfall was noted for each entry. No stage-discharge calibration was made for the staff gage.

Sunday River at Covered Bridge

An enameled "USGS style" staff gage was mounted on a fence post and driven into the streambed near the northeastern concrete abutment of the new Sunday River Road bridge, just downstream of the covered bridge. A volunteer monitor made 11 weekly observations between June 13, 2003 and August 11, 2003, at which time she thought the staff gage had either washed away or was submerged. A subsequent visit found the staff gage intact.

Flow was measured near the covered bridge on three occasions. The range of flows is probably too narrow to develop a meaningful stage-discharge relationship, except for low flows.

Date	Time	Gaged Flow (cfs)
June 3, 2003	1:30 p.m. – 1:55 p.m.	45
June 23, 2003	1:34 p.m. – 1:52 p.m.	31
August 20, 2003	10:40 a.m. – 11:02 a.m.	42

Observed staff gage readings varied between a minimum of 0.82 feet (July 14) and 1.86 feet (June 13). On August 11 the staff gage was observed as being overtopped, which would have been a reading greater than 3.50 feet. Debris trapped on the staff gage also indicated high water levels (greater than 2.0 feet on the staff gage) during other periods.

Barkers Brook near Cross-Country Ski Bridge

No volunteer monitoring data was collected and forwarded for the staff gage located on Barkers Brook. Flow in the brook was gaged on three occasions but cannot be compared to any monitoring data. The gaged flows are as follows.

Date	Time	Gaged Flow (cfs)
June 3, 2003	5:00 p.m. – 5:34 p.m.	2.1
June 23, 2003	3:29 p.m. – 3:35 p.m.	1.3
August 20, 2003	3:00 p.m. – 3:15 a.m.	1.0

Sunday River at Harringtons

With the permission of the Harrington family, a recording water level logger and staff gage were installed by Kleinschmidt Associates just downstream of the rip rap berm on their property, near the site where the river cut a new channel through the Harrington's farm field. Five gage measurements were made at this site to establish a stage-discharge relationship for the recorder.

Date	Time	Gaged Flow (cfs)
June 3, 2003	11:47 a.m. – 12:12 p.m.	47
June 5, 2003	2:51 p.m. – 3:20 p.m.	43
June 6, 2003	9:25 a.m. – 9:50 a.m.	129
June 23, 2003	4:30 p.m. – 4:50 p.m.	32
August 20, 2003	3:47 p.m. +	39

The transducer recorded continuously between June 3, 2003 and June 23, 2003. The level logger was checked on June 23, 2003, data was retrieved onto a laptop, and the gage ran continuously until August 6, 2003 at which time a high flow event occurred that apparently overtopped the transducer and stilling well, wetting the transducer through its vents. Data was able to be retrieved up to August 6, 2003, although the data on that last day is suspect.

The gage at the Harrington site captured hydrographs for four significant flow events and failed during a fifth event. The first significant flow event occurred on June 6, 2003, in response to an unknown amount of rainfall the day before. **Figure 5.18** illustrates the rise in flow at the Harrington site. According to the level logger, the water level rose approximately 0.72 feet in 15 hours, resulting in a peak around 8:30 p.m. on June 6th.

Using the stage-discharge relationship developed for the gage, the peak flow for this event was estimated to be approximately 130 cfs. As a check, flow was also prorated from the Wild River streamgage using a regression between Wild River gage flows and flows gaged at the Harrington site. The regression was made using a record extension technique used elsewhere in Maine by the USGS, as described in the report "Record Extension and Streamflow Statistics for Pleasant River, Maine"

(1999). The regression is considered approximate, since only five flows were compared, although the correlation coefficient (r = 0.98) is very good. As illustrated on **Figure 5.18**, the peak flow predicted by the gage proration is approximately 150 cfs. There is some difference between the shape of the hydrographs, but this could be due to the location, timing and amount of precipitation during the event. Overall, the hydrographs track remarkably well.

The second significant flow event occurred on June 14, 2003. (Upstream in the watershed, near Simons Brook, one volunteer monitor recorded a rainfall of 0.9" by 11 p.m. on June 13th and an additional 1.0" of rainfall by 4:00 p.m. on June 14th.) **Figure 5.19** illustrates the rise in flow at the Harrington site. According to the level logger, the water level rose approximately 2.88 feet in 8 hours, resulting in a peak at 10:30 p.m. on July 14 th. This is a very fast rate of rise. The water levels receded more gradually at the site, but still relatively quickly.

Using the stage-discharge relationship developed for the gage, the peak flow for this event was estimated to be approximately 400 cfs. Also as a check, flow was also prorated from the Wild River streamgage using a regression between Wild River gage flows and flows gaged at the Harrington site. As illustrated on **Figure 5-19**, the peak flow predicted by the gage proration is approximately 350 cfs. The biggest difference is on the falling limb of the hydrograph, where the datalogger predicts a slower flow recession than the prorated gage data. Overall, the area under the hydrograph developed by the level logger data is greater, implying that the Sunday River watershed had a greater runoff volume for the storm than the Wild River per square mile of drainage area. This could have been due to more precipitation falling in the Sunday River watershed than in the Wild River basin, or any number of hydrologic variables that affect runoff.

A third significant flow event occurred around July 11, 2003. Upstream in the watershed, volunteer monitors noted that it was "raining heavy" on the 11th, with one monitor reporting 1.1" of rain on that day, another monitor reporting 1.3". According to the water level logger, the river stage at the Harrington site rose 0.47 feet in approximately 13 hours.

Figure 5.20 plots the hydrographs for the site. Using the stage-discharge relationship developed for the gage, the peak flow for this event was estimated to be approximately 70 cfs. Also as a check, flow was also prorated from the Wild River streamgage using a regression between Wild River gage flows and flows gaged at the Harrington site. As illustrated on **Figure 5.20**, the peak flow predicted by the gage proration is also approximately 70 cfs. Note that the timing and magnitude of the peak flow is very similar using either a stage-discharge relationship or flows prorated from the Wild River streamgage. Again, however, the receding limb of the hydrograph from the water level logger has higher flows than from the prorated flow data.

A fourth significant flow event occurred around July 24, 2003. Volunteer monitors elsewhere in the Sunday River watershed noted rainfall of approximately 1" on July 23 and 24, as well as smaller amounts of rainfall a few days before. **Figure 5-21** plots the hydrographs for the site. Compared to previous storms, the hydrograph estimated from level logger data did not track as well to flow data prorated from the Wild River streamgage. Using the stage-discharge relationship developed for the gage, the peak flow for this event was estimated to be approximately 70 cfs. The peak flow predicted by the proration from the Wild River is approximately 45 cfs. Note that the timing of the peak flow is very similar using either technique. One possible explanation is that rainfall distribution differed greatly between the Sunday River and Wild River watersheds for the event. This is supported by the fact that Merrill Brook did not rise significantly on July 24th, perhaps indicating a storm that concentrated precipitation at a lower elevation, closer to the Androscoggin River. Note that the water level logger at the Harrington site picked up another peak on July 28th which was not reflected in the Wild River streamgage data, almost certainly due to very localized precipitation in the Sunday River basin.

The water level logger was unfortunately inundated during the largest flow event of the summer 2003 season. Significant rainfall around August 6 th and August 10 th created a double-peaked hydrograph for the Wild River, as illustrated on **Figure 5.22**. The water level logger was inundated on the rising limb on the hydrograph for the first peak, on August 6th. The water level rose nearly 5.0 feet in 8 hours before the records stopped.

The hydrograph from Merrill Brook (**Figure 5.17**) indicates two strong peaks, the timing of which is close to the hydrograph from the Wild River streamgage. Therefore, it is believed that the August events, a few days apart, soaked a large region in western Maine that would have covered both the Wild River and Sunday River drainages. For the Sunday River, the only estimate we have for the peak flows is from data prorated from the Wild River. Based on the proration, peak flows for the Sunday River at Harrington's would have been approximately 2,100 cfs (early on August 6th) and 2,500 cfs (August 10th).

One of the best pieces of information the water level logger at the Harrington site provided was an understanding of the timing of peaks in the larger watershed. The following table summarizes the timing of the peaks.

Event	**Merrill Brook Peak**	**Bull Branch Peak**	**Sunday River Peak**
July 11 th	1:00 – 1:30 p.m.	3:00 – 3:30 p.m.	9:13 – 9:43 p.m.
July 24 th	no appreciable peak	10:30 p.m.	4:58 – 5:28 a.m. (July 25)

For the July 11th event, Sunday River flow at Harrington's peaked approximately 8 hours after the peak in Merrill Brook and approximately 6 hours after the peak at Bull Branch. For the July 24th event, Sunday River flow at Harrington's again peaked nearly 6 hours after the peak at Bull Branch. This is remarkably short spacing between the peaks, given that the channel length between the Bull Branch and Harrington gaging sites is nearly 8 miles. Again, this points out the flashy response of the Sunday River and its tributaries to significant rainfall events.

5.5 Hydrologic Analyses

Although the period of record was relatively short, the hydrologic data did provide some important information about the Sunday River watershed. Major findings are summarized below. As more data is collected in the watershed, or restoration projects are being designed, the collected data may be further analyzed or supplemented with additional data.

1. **Flow peaks from summer precipitation events are very sharply peaked and move quickly through the watershed.**

   Although this was not a surprise, given the steepness of the basin and the lack of wetlands, the flow data proved how quickly water levels rise and diminish in the watershed. High flows develop very quickly and move very rapidly through the watershed in response to significant rainfall.

   The flashy nature of the watershed has many significant consequences, although more detailed study is required to quantify these effects.

   - Watershed activities that are known to sharpen flow peaks—such as urbanization, paving and construction that increases impervious area, channel straightening or hardening, wetland filling, bypassing of floodplains, extensive logging and stormwater acceleration—would be even more significant in a basin that is predisposed to sharp flow peaks naturally.

   - High flows develop quickly in the watershed, with the flood peak traveling through the watershed in several hours. This highlights the need for good floodplain management, since high flow warning systems designed to protect development in the floodplain would not provide any meaningful amount of time for warning and evacuation.

   - Since flood flows pass very quickly through the basin, natural or built features that attenuate peak flows (e.g., floodplain wetlands, ponds) do not have to retain flows for long periods of time. This is especially important for designing or restoring floodplain wetlands, since it influences the plant composition of these floodplains. (For example, red maples can tolerate short periods of occasional flooding, but not long periods of standing water.) For a basin with sharply peaked hydrographs, any wetland feature that provides flow attenuation or storage is probably significant.

- Sharply peaked hydrographs imply that coarse sediment is probably mobilized and redeposited within a short period of time in any given reach. The steeper the basin, the higher the velocity and the shallower the depth for any given flow, so that sediment transport may be significant for several flow events in any given year, not just a spring snowmelt event. A more frequent "sorting" of coarse substrates can influence aquatic habitat for fish and macroinvertebrates.

2. **The Wild River streamgage may be a good indicator of high flow events in the Sunday River watershed, especially for large rainfall events not associated with snowmelt.**

Although this is only based on a limited comparison of flow data, the similarity between the Wild River and Sunday River basins in drainage area, slope, elevation, geographical region, percent wetlands and maybe even land cover implies that the watersheds should have similar hydrology. The significance is that a long term gage record is available for the Wild River but not the Sunday River. For the few storm events studied, the timing of peak flows in the Wild River at the streamgage and in the lower Sunday River is remarkably close. For a storm that covers a large region in western Maine, it is therefore possible to watch the real time flow hydrograph for the Wild River on line through the USGS website and get a sense of flow response in the lower Sunday River as well. More data is needed to compare the two watersheds during snowmelt events. By prorating streamflow data from the Wild River to the Sunday River it is also possible to develop statistics for flow frequency, such as low flows, annual and monthly median flows, and floods.

3. **USGS regression equations widely used to estimate peak flows for selected floods may underestimate peak flows in the Sunday River watershed.**

As discussed earlier, the 100-year flood flow published in the Town of Newry Flood Insurance study may be closer to a 5-year flood than a 100-year flood, based on comparisons with flow statistics for the Wild River streamgage. This could imply that a large amount of floodplain will end up being unidentified (and therefore unregulated) in the Town of Newry. This could lead to more development in the 100-year floodplain, including more development in floodplain that is not covered by flood insurance and problems such as the loss of floodplain storage, diminishment of flood attenuation, loss of wildlife habitat and degraded water quality. There is also the potential for undersizing structures such as culverts and bridges during design. It is recommended that flow estimates for floods be verified independently of the USGS regression equations, and the Flood Insurance Study be revised if necessary.

4. **Recent channel forming events, such as the avulsion at the Harrington property, may partly have a hydrologic basis.**

Watershed activities such as land clearing, new roads, paving, construction of buildings and logging can undoubtedly contribute to some of the changes seen in the Sunday River in recent years, such as increased sedimentation, bank instability, and even changes in channel geometry and planform. There is also some evidence that suggests that the region may have seen several higher than normal flows in recent years, and this could be a contributing factor to these changes. According to the USGS streamgage data for the Wild River, which has similar hydrology to the Sunday River, the following information can be gleaned.

Wild River at Gilead, Maine Streamgage

Water Year[1]	Peak Flow (cfs)	Date	Recurrence Interval[2]
1996	24,500	October 22, 1995	50-year
1997	8,750	October 21, 1996	2-year
1998	19,200	June 14, 1998	17-year
1999	18,100	September 17, 1999	13-year
2000	11,200	April 9, 2000	3-year
2001	8,060	December 17, 2000	< 2-year
2002	9,250	April 14, 2002	> 2-year

[1] October through September
[2] Approximate, Estimated from Published Peak Flow Data (USGS, 1999)

It is possible that as more streamgage data is collected the flood flows for the Wild River may be adjusted upward. However, the current period of record is nearly 40 years, which is probably long enough to develop meaningful streamflow statistics. The record indicates several high flows in recent years, including events that probably would have transported considerable sediment loads and changed the channel geometry. Assuming that flows of similar recurrence intervals occurred in the Sunday River watershed, some channel response was probably inevitable.

5. **High flow events associated with summer storms (including late season tropical storms) can be as significant as events associated with snowmelt.**

Given the mountainous subbasins in the upper Sunday River watershed, it was generally assumed that runoff events associated with snowmelt (midwinter or spring thaws) are the greatest cause of high flows. As evidenced by the Wild River streamgage data, that is not necessarily true. Annual peak flows for many years of record were greatest in summer or early fall months, and were probably associated with intense summer thunderstorms or tropical storms. The two highest flows of record in the Wild River (28,300 cfs and 24,500 cfs) occurred on October 24, 1959 and October 22, 1995, respectively. Flow gaging during the summer of 2003 did not capture any events approaching a 2-year flood, but it did illustrate the rapid response of the Sunday River and its tributaries to any rainfall exceeding one inch, with sharply peaked hydrographs.

6.0 SEDIMENT BUDGET

6.1 Method

An overall absolute sediment budget for the Sunday River watershed is beyond the scope of this project. Still, analysis of the field observation, detailed assessment, historic assessment and sediment transport modeling can provide general trends and relative quantification of potential sediment input, output and storage within the watershed.

6.2 Sediment Supply and Transport

The sediment transport modeling component of the study provides general patterns of sediment routing (i.e. sources, transfer areas and sinks) within the watershed. Information from the detailed sites provide the values necessary to characterize sediment transport through those reaches at bankfull conditions, which is expected to represent an event of long duration that would do the most cumulative work. If it is assumed that bankfull events between reaches occur at relatively similar intervals (return periods of 1.5 to 2 years) then comparison between reaches is also appropriate and the information provides insight into potential transport between zones of the watershed. Due to the distribution of detailed sites, this approach provides the potential relative contributions of sediment at the bankfull or effective discharge from most of the sub basins and at key locations along the main branch of the Sunday River. Several modeling approaches are available to assess sediment load and the different components of the total load transported (i.e., suspended load, bed load). In this case, only potential bed load is modeled as it provides the most important component from a geomorphic perspective. The bed load also likely comprises the majority of the material transported through the system; this is supported by the coarse bed material found along almost all the reaches. Also, this material is the most important component with respect to the channel forming (e.g., riffles and bars). There are numerous approaches to modeling bed load transport; all with their own strengths and weaknesses. Here a Bagnold (1973, 1977, 1980) approach is taken to model bed load. This simple method is based on the concept of stream power (work); that a portion of the potential energy to do work will be utilized to transport sediment. The simplicity of the method allows the model to be applied from the bankfull hydraulic values that were previously calculated (i.e. bankfull geometry, slope and velocity). As only relative contributions are needed from this modeling exercise, whether the model in fact provides accurate absolute values is not relevant. Also, the model results represent a potential bed load as the model assumes that the capacity of the channel is less then the available supply. In supply limited areas the potential transport over-predicts bed load transport. **Table 6.1** provides model output from the bankfull sediment transport modeling exercise, while **Figure 6.1** illustrates the spatial variation in transport rates and median grain size. First, it is

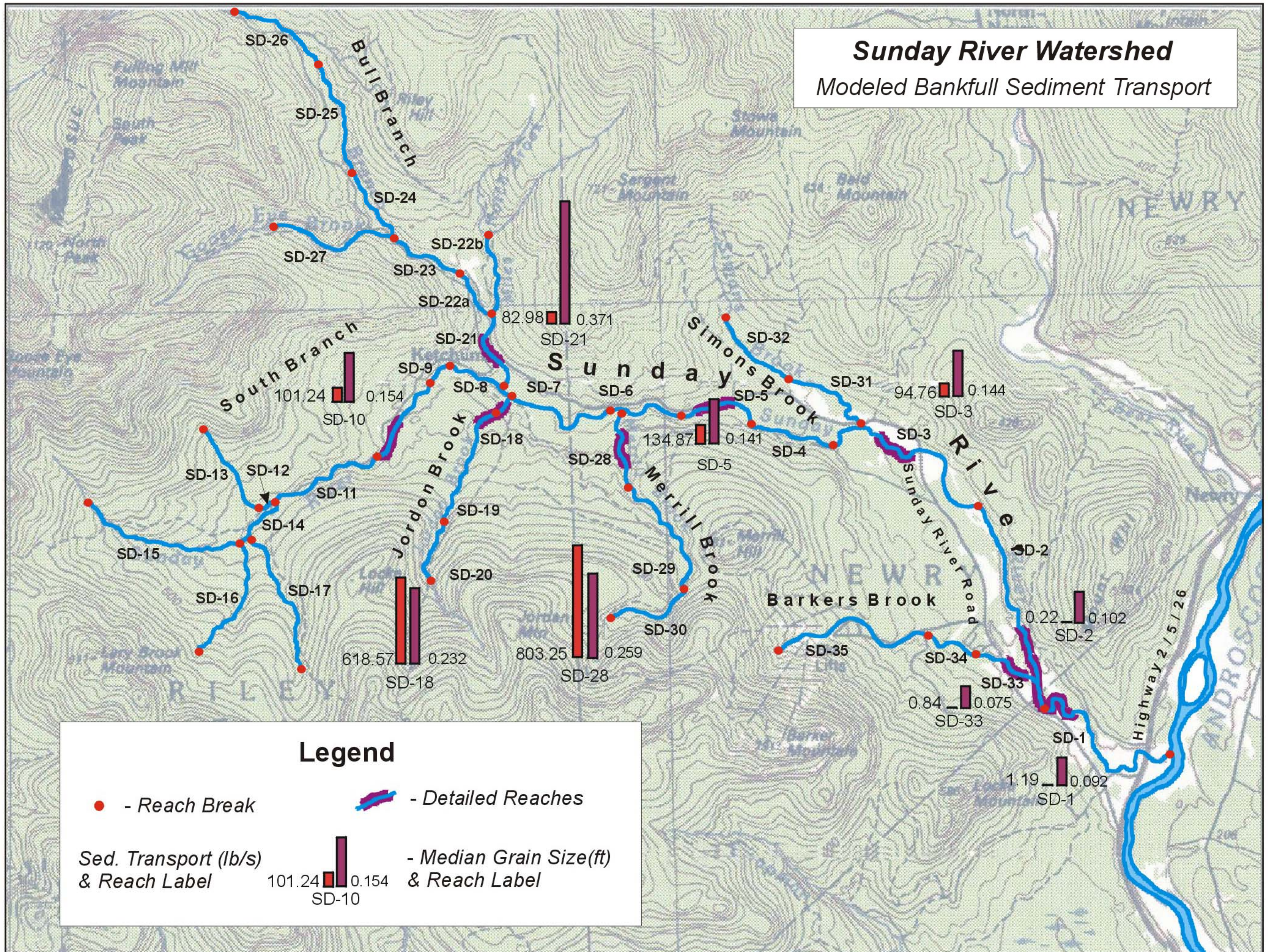


Figure 6.1. Modeled potential bed load assessed at the detailed sites.

apparent that although the lower order tributaries generally have larger substrate, they are potentially efficient at transporting the available materials. The higher order, downstream channels generally have lower relative transport capacities (the amount of material) and competencies (size of material) then the smaller upstream reaches. This is generally a product of channel gradient. The reduced ability to transport sediment in the lower reaches means these reaches act as sinks for sediment. It should be noted that the calculations provided are potential transport rates and where sediment supplies are limiting, which is often the case in smaller headwater channels, the actual sediment load can and will be substantially lower then the potential modeled load. Therefore, the actual difference in bed load transport among the tributary channels and between the tributary and the main channel is likely not as dramatic as the modeling suggests.

As previously noted, oversupply of sediment leads to wider, shallower channels with characteristics of a braided channel (i.e. multiple channels, point bar, mid channel bar and island development) and tend to show signs of planform adjustment, channel widening and aggradation. The observations from the rapid assessments indicate aggradation and widening are dominant adjustments in the lower reaches of the watershed which matches well with the bed load modeling results; while, with only a few exceptions, symptoms of degradation and/or channel widening were noted along the majority of tributary channels.

Table 6.1. Bedload transport rates at bankfull conditions for the detailed site.

Reach	Width (ft)	Bedload lb/s	D50 (inch)
SD-1	75.85	0.49	1.102
SD-2	94.85	0.29	1.220
SD-3	126.15	17.30	1.732
SD-5	117.98	134.87	1.693
SD-10	48.06	101.24	1.850
SD-18	28.64	618.57	2.783
SD-21	48.06	82.98	4.449
SD-28	39.11	803.25	3.106
SD-33	26.87	0.84	0.894

6.3 Erosion Analysis

Due to past alterations to the channels and land cover there have likely been periodic and relatively rapid changes in available sediment supply due to both natural occurrences (i.e., large flow events) and human impacts such as logging. There have also likely been temporal and spatial variations in local hydrology due to shift in land use practices, such as the reduction in logging and intensive agriculture and the development of ski facilities. These changes in sediment regime and hydrology, along with historic alterations of channels, such as those occurred as a result of gravel extraction, logging runs and channel straightening/training, likely exacerbates the rate of natural adjustment expected due to a reaches relative position and function within the watershed (i.e., production, transfer, or depositional). This leads to the high level of channels in adjustment and transition within the watershed. Although the potential bed load modeling indicates large inputs from the headwater systems, this modeling does not account for actual available sediment. The amount of bank erosion and the historic release of sediment suggest that additional sediment inputs to the lower reaches, which show substantial signs of aggradation, may, in part, be a product of sediments sourced from the mid-reaches, which presently, likely have an oversupply of sediment. The erosion from these upper main channel reaches, given the scale, would produce a substantial amount of material. In order to be effective, restoration measures need to account for and address local channel adjustments and be cognizant of upstream and downstream influences and impacts.

7.0 DISCUSSION

7.1 Channel Form and Function

To link the observations of channel form, process and adjustments, several key concepts need to be presented. First, as previously outlined, watersheds can be divided conceptually into zones of production, transfer, and deposition, from upstream to downstream dependent on dominant form and function (see **Figure 4.3**). Headwater (production) zones are characterized by steep gradients, little in the way of alluvial storage and floodplain, and net loss or production of sediment which is transported to the downstream channels. Transfer zones are characterized by wide floodplain, moderate gradients and meandering patterns. The floodplains provide areas for temporary storage of sediment. Generally, there is no net gain in sediment within the system. Further downstream, the depositional zone is characterized by "flat" gradient, strong meandering pattern and net sediment storage. The geomorphic evidence presented here (observation of form and dominant processes) indicate that the Sunday River catchment generally fits this conceptual model.

A second, but equally important concept is Lane's Balance, or the concept of channel equilibrium. This concept, which is visually illustrated in **Figure 7.1**, assumes that channels work to produce equilibrium between erosive and resisting forces acting within the channel. This balance can be simplified to four parameters: sediment discharge, sediment particle size, stream flow and stream slope. Equilibrium occurs when all four are in balance. If one changes, there must be a proportional adjustment in the other parameters before new equilibrium is reached. These adjustments can occur over a range of time scales and in many cases systematic adjustments may be observed long after the initial perturbation has occurred. These observations are useful for making qualitative predictions and in explaining observed adjustments in channel geometry. As the larger downstream reaches 'feel' the accumulative adjustment of the upstream reaches downstream impacts can be dramatic. This is particularly true when the upstream reaches are adjusting in similar ways to similar pressures, such as oversupply of sediment due to logging and land clearing practices.

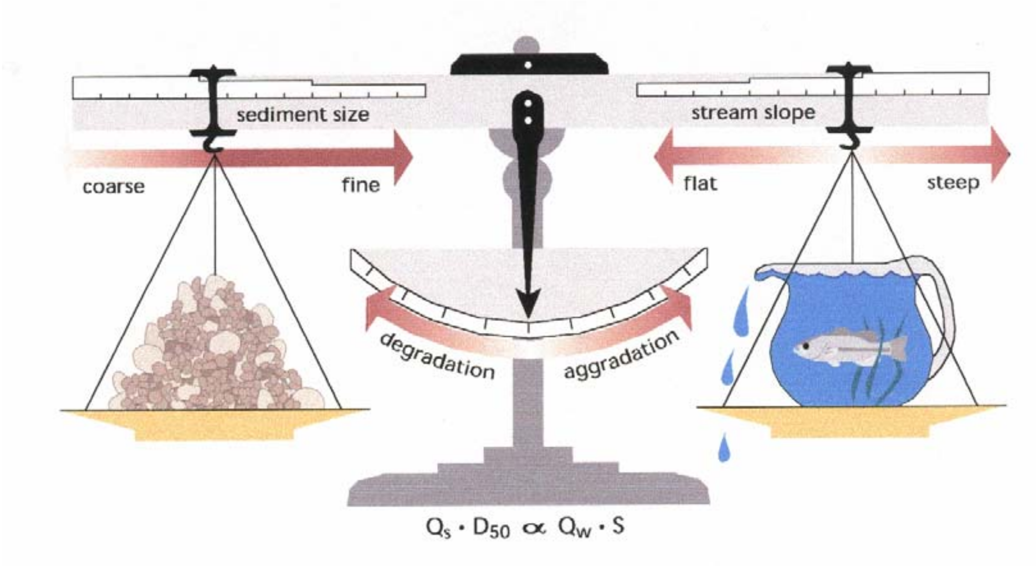


Figure 7.1. Lane's balance (source: Rosgen, 1996 in USDA, 1998)

Along the lower reaches of the Sunday River watershed channel widening and aggradation in lower were prevalent. The channel widening is likely a product of the channel attempting to retain its cross-sectional area even with systematic infilling. This may also be related to recent (over the last 10 years) high flow events.

Three general trends were observed within the Sunday River tributaries. First, a linkage was observed between degradation and widening, indicating that reaches have a capacity and competency to erode and transport bed and bank sediments. Secondly, there were reaches where widening and aggradation dominated, indicating that reaches could erode their banks but without competency to transport sediment through the system. This may also indicate an oversupply of sediment and an attempt by the channel to maintain cross-sectional area. Finally, reaches displayed evidence of degradation and aggradation. This is likely an indication of dynamic bedload dominated channels which actively erode and transport sediment through 'pulses' (i.e. bars and other depositional features).

The hydrology study highlighted that previous work likely underestimates the magnitude of given return flows. This, along with the evidence that previous 'high' flow storm events may in fact characterize more frequent flow events, provides evidence that the Sunday River is a very dynamic high energy watershed. These observations, in addition to anecdotal evidence of high flows and the historic assessment that illustrated sediment activation as a result of past land use practices, indicates that there is presently an over-supply of sediment within the system that can be readily reactivated. These points need to be addressed if restoration is to be effective within the watershed.

8.0 RESTORATION STRATEGY

Based on the work undertaken and the results that have been discussed, it is apparent that some restoration work is warranted within the watershed. Two approaches to restoration, based on the scale of works, can be taken. The first, *ad hoc* or patchwork restoration which would generally consist of small scale, simple and inexpensive restoration projects, such as small scale bioengineering projects to stabilize sections of channel banks in order to decrease sediment supply and improve local habitat (i.e., greater riparian cover and reduced infilling of pools). As the impacts to the lowest reaches are an accumulation of upstream impacts, numerous small scale projects may lead to greater stability downstream. At the other end of the spectrum are large scale restoration projects involving wholesale change to channel configuration. These projects tend to involve large equipment, more detailed design and greater cost. The scale or strategy is dependent on the relative degree of channel disturbance, risk to property or infrastructure and potential to improve stream health and/or stability.

Figure 8.1 displays the spatial distribution of sites which are considered priority based on a combination of the rapid assessments, monitoring, and detailed field investigations. This spatial distribution of sites does not account for risk to property or infrastructure, or local community concerns. Based on the results of this work, any restoration work should be directed at controlling sediment input in the upper part of the watershed and main tributaries and controlling runoff from the headwaters through better conveyance systems or storage BMP's (Best Management Practices). Within the main Sunday River, there are issues of channel migration, excessive bank erosion and sediment accumulation. While the large-scale removal of sediment may be beneficial in some reaches, it is a large and expensive proposition, and without control of upstream sediment sources, the success of the sediment removal is questionable. Focused stabilization work may be a better long-term solution, which may provide some enhancement to aquatic habitat. One must be aware, however, that the sediment is attempting to move downstream to the Androscoggin River. Through the sediment migration, there will be sections of the river that will lose capacity and be more prone to avulsions.

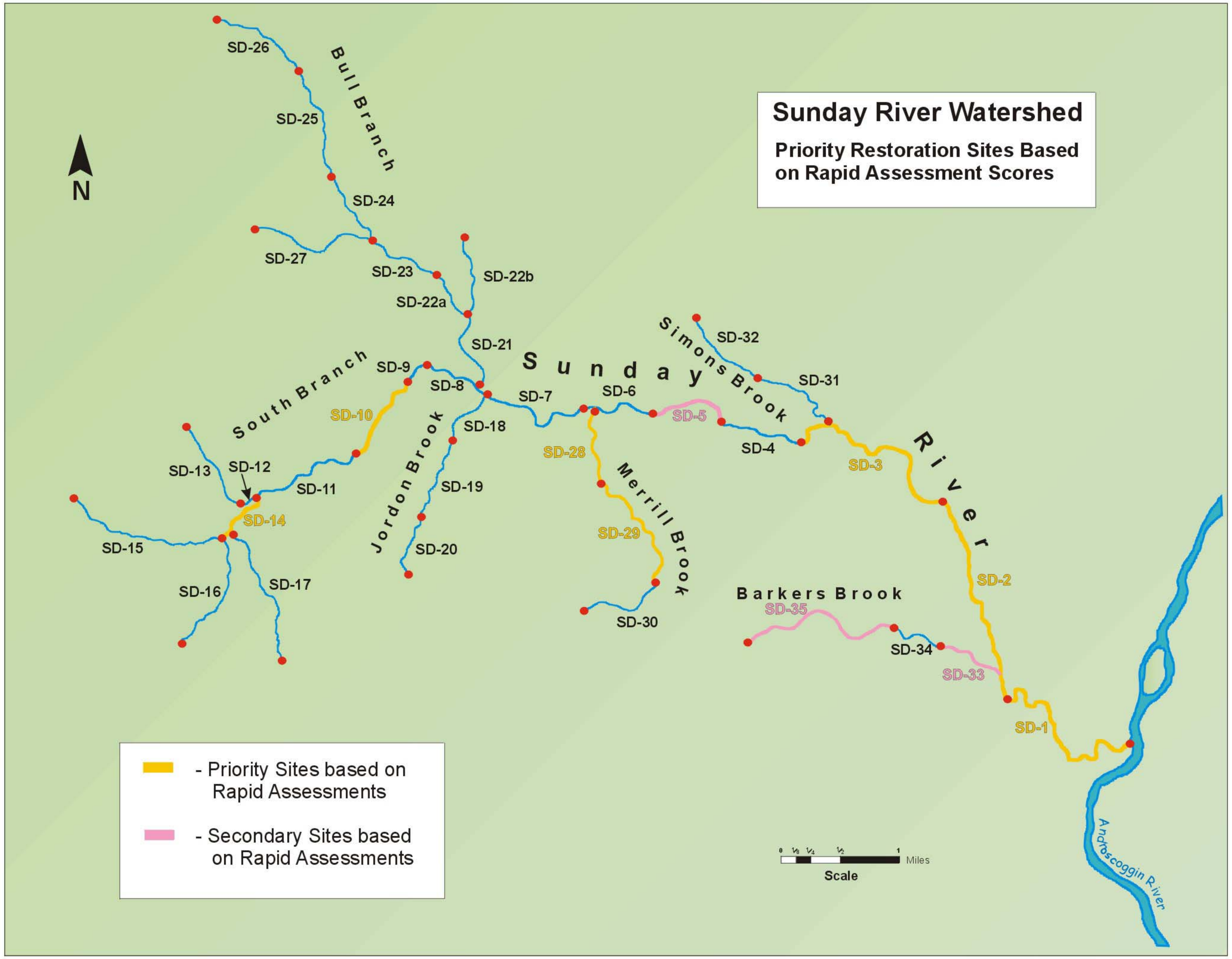


Figure 8.1. Reaches of the Sunday River selected as priority areas based on a combination of the rapid assessment scoring.

8.1 Restoration Approach

Given the complex nature of the watershed and the active processes occurring within it, developing a true priority list for restoration is difficult. That being said, to provide an overall improvement in the watershed, reaches were prioritized for restoration based on their relative degree of channel disturbance, risk to property or infrastructure, and potential to improve stream health and/or stability. In prioritizing sites, an attempt was made to establish a balance between improving basic channel function and habitat concerns while accommodating local hazard issues.

From reviewing the existing conditions within the watershed, two specific potential restoration themes were identified. The first is associated with several of the smaller tributaries. These smaller channels and tributaries, particularly along Barker's Brook and Merrill Brook, appear to be adjusting (i.e. widening, downcutting) due to changes in land use patterns which have influenced their hydrologic regime. In these catchments, development of water retention and detention features would allow expansion and creation of local wetland features and provide reduced peak flows. Furthermore, channel enhancement through the installation of riffle-pool sequences would reduce entrenchment and create more dynamically-stable channel systems. This would reduce channel erosion and decrease sediment load to the lower reaches.

The second theme develops from a recurring observation along many of the reaches of the Sunday River, which was the absence of deep pools, due, in part, to aggradation and bank erosion. Habitat improvements to the channel and greater floodplain could be provided by projects that provide minor reworking of channel geometry, including lowering of banks for better connectivity between channel and floodplain, deepening of pools to provide better low flow refuge and greater channel variability (diversity of habitat), and sculpting of bar material to reduce channel curvature and bank erosion rates. This would increase local shear by increasing gradients and water depth in the channel, thus improving sediment conveyance. Better connectivity between floodplain and river will enhance those habitat features in the floodplain. These improvements could be strategically done in areas where the river migration is also a hazard to permanent structures (i.e. roads) and property.

8.2 Priority Sites

A range of work could be undertaken, from the small-scale, to control erosion or sediment from logging roads, to moderate size, that involves more materials, time and planning, to the large-scale. Listed below are eight reaches where restoration is highly recommended. The list is in reach order as there is no priority sequence. For each reach, a summary of problems and generic approaches are provided. Within **Appendix E**, site specific preliminary designs for areas within these reaches are presented. These sites represent a range of possible work to address the various problems within the watershed, and thus provide examples of the type and nature of restoration that could be undertaken in the future.

<u>SD-1</u> – This reach has several tight meanders that are experiencing rotation migration and have a high tendency for avulsion. There is also extensive amounts of severe bank erosion, including several areas where private property and structures are threatened. This reach is accumulating sediment; given the low gradient and upstream sediment production. Thus, restoration should stabilize banks where possible and increase the channel capacity to reduce the risk of avulsions.

<u>SD-2</u> – This site had low stability scores compared to other reaches within the watershed and the channel has had a historic tendency to adjust its channel planform rapidly, which continues to have negative impacts on local landowners, as is occurring at the Harrington Farm Property. This section of the river would benefit from increased channel capacity and bank stabilization. Given the wider floodplain, there are also areas where re-establishing historic floodplain wetlands is possible.

<u>SD-3</u> – Major bank erosion and aggradation were characteristic of this reach. There appears to be a high volume of sediment accumulation in this area which has greatly reduced pool depths which in turn has caused a reduction in fish habitat. Potential exists for enhancing pool-riffle sequences and bar sculpting to provide more diverse habitat, better connectivity (reduce entrenchment) with the floodplain and potential wetland features, and improved sediment conveyance.

<u>SD-5</u> – Although this reach is considered a secondary priority with respect to fisheries and geomorphic concerns, it is a potential area for restoration and stabilization due to the erosion adjacent to the Outward Bound Camp. Bank stabilization or other forms of channel work will most likely be required as a near term or long term solution for the bank erosion along the road.

Potential exists for enhancing pool-riffle sequences and bar sculpting to provide better and more diverse habitat and better connectivity (reduce entrenchment) with the floodplain and potential wetland features. The designs would also improve channel stability and reduce risk to property.

<u>SD-10</u> – Channel adjustment and aggradation were characteristic of this reach. There appears to be a high volume of sediment accumulation associated with an old timber dam. This sediment accumulation may have reduced pool depths which in turn has caused a reduction in fish habitat. Potential exists for enhancing pool-riffle sequences and bar sculpting to provide more diverse habitat, bank stabilization, better connectivity (reduce entrenchment) with the floodplain and potential wetland features, and, improved sediment conveyance.

It is acknowledged that there are other timber dams within the watershed (SD-5; SD-20). These dams are deteriorating in a similar fashion to the one described above. These sites are suitable areas for restoration provided that the sediment accumulated upstream of the structure remains in place. The application of rocky ramps/riffles in reducing the grade and retaining the sediment has been successful in other dam removal projects. Thus the work shown in **Appendix E** for SD-10 is also applicable for the other dam sites.

SD-14 – This reach appears to be experiencing a significant degree of adjustment as it is the reach immediately downstream of the confluence of several significant tributaries. Potential exists for enhancing pool-riffle sequences and bar sculpting to provide more diverse habitat, better connectivity (reduce entrenchment) with the floodplain and potential wetland features, and improved sediment conveyance.

SD-28 and/or SD-29 – Merrill Brook appears to be influenced by adjacent land uses such as the nearby golf course and snowmelt runoff from the ski hills. As outlined in the previous section, these systems would benefit from works to limit the long term impact associated with land use change. The adjacent land provide a potential location for the development of retention and detention ponds for stormwater management and wetland creation. Other enhancements could include installation of riffle-pool or cascade-pool sequences to reduce entrenchment, decrease erosion and provide variability in aquatic habitat.

SD 33 – This is the lower portion of Barkers Brook. There is extensive bank erosion throughout this reach. The channel below the Sunday River Road bridge has lowered creating a barrier to fish passage. In other areas, the channel has accumulated high amounts of fine sediment. The restoration work would improve channel planform and dimensions to ensure better conveyance of sediment while improving aquatic habitat. Opportunity also exists to create some hydrological storage on the floodplain and to complete some bank re-grading in order to stabilize the banks while improving the functional connection between the channel and its floodplain.

Additional Sites – There are certainly numerous other minor sites where channel work could be undertaken to benefit the river system. This work is more local scale and could be completed by volunteers. Typically this work would consist of bank stabilization and through various bioengineering techniques (see **Appendix F** for typicals and explanations). Other specific sites include bank stabilization on Barkers Brook (SD-35) and benching/bank treatments on portions of the main stream (SD-7). Many other smaller tributaries and logging roads would benefit from controlling erosion and thus sediment input into the Sunday River system (see Oxford County – Watershed Surveys).

This work, as well as riparian zone plantings, could be implemented at any time, and, as frequently as possible. Given the small-scale nature of the work, a substantial amount would need to be implemented before any positive cumulative effects were recognized within the watershed. Thus, this 'local' work should be prioritized to the sites listed above. The work, summarized in **Appendix E,** would require more effort and a larger budget. As a result, it may not be possible to implement these projects as readily and/or consistently as the smaller scale work. The re-introduction of large woody debris experiments completed in the White Mountain National Forest could also be implemented in the upper portions of the Sunday River. There is little doubt that this work would offer immediate benefits to the local aquatic habitat and most likely result in positive gains to sediment retention. However, many of the tributaries are rapidly adjusting and the woody debris experiments may not be as successful due to a lack of channel stability at the reach scale. This being said, any opportunity to undertake an experiment should be accepted, implemented and monitored, as the results will undoubtedly be informative and applicable to other areas.

In addition to the preliminary concept plans (**Appendix E**) and the bioengineering treatments (**Appendix F**), there are numerous other sources that could be referred to when preparing restoration solutions. These include the USDA Stream Corridor Restoration Handbook (1998) as well as numerous web sites, notably from various States. Obviously, before undertaking the work, proper communication with the regulatory agencies and local landowners is critical. If possible, some additional preparatory work should be completed to ensure the work addresses the underlining problems and active processes at the site.

9.0 FUTURE WORK

A fairly comprehensive assessment of the physical processes occurring within the Sunday River watershed has been completed. Based on the assessment, field work, monitoring and analyses, substantial information on channel processes and the overall watershed behavior has been obtained and general and site specific restoration recommendations were developed. Through the course of the assessment, several specific questions have been asked. One question pertains to the effects of the snow-making process at local ski resorts. The entire water removal, storage and subsequent runoff were reviewed, albeit at a relatively coarse level. The water taking from the river does not likely have any real implication to the physical processes and ecology of the downstream reaches. The effects of increased runoff from ski slopes as a result of snow-making activities are much more difficult to assess and would certainly require a more specific investigation.

One limitation of the study was the short period of observation. In light of the hydrological and geomorphic observations, it would be constructive if the installed monitoring sites were revisited at least once a year. This would provide additional information on rates of channel processes.

Any restoration works completed should be documented and monitored. As there will likely be numerous small scale restoration works, it provides an opportunity to identify the most effective method to monitor and evaluate each project.

It is felt that a sound understanding of the watershed, with respect to fluvial geomorphology, hydrology, erosion and sediment transport has been obtained. This information and understanding is available to help address management and planning issues as they arise. These would include the implications of any future forest management. For instance, if the area of timber harvest is known, it is likely that information on the downstream reaches is available, and the relative sensitivity can be determined. This information could then be used to provide specific recommendations on buffering, timing or desired cutting. Furthermore, the data in this study could be used as a reference to monitor the effects of the timber harvest. This application could also be made to specific development proposals, including recreational uses (e.g., golf courses), residential or commercial developments.

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APPENDIX A

Reach SD-1. Note the large amounts of gravels and cobbles deposited in this area.

Reach SD-2. Monitoring site on the main channel near the Harrington property.

Reach SD-2. Main channel adjacent to snow making ponds.

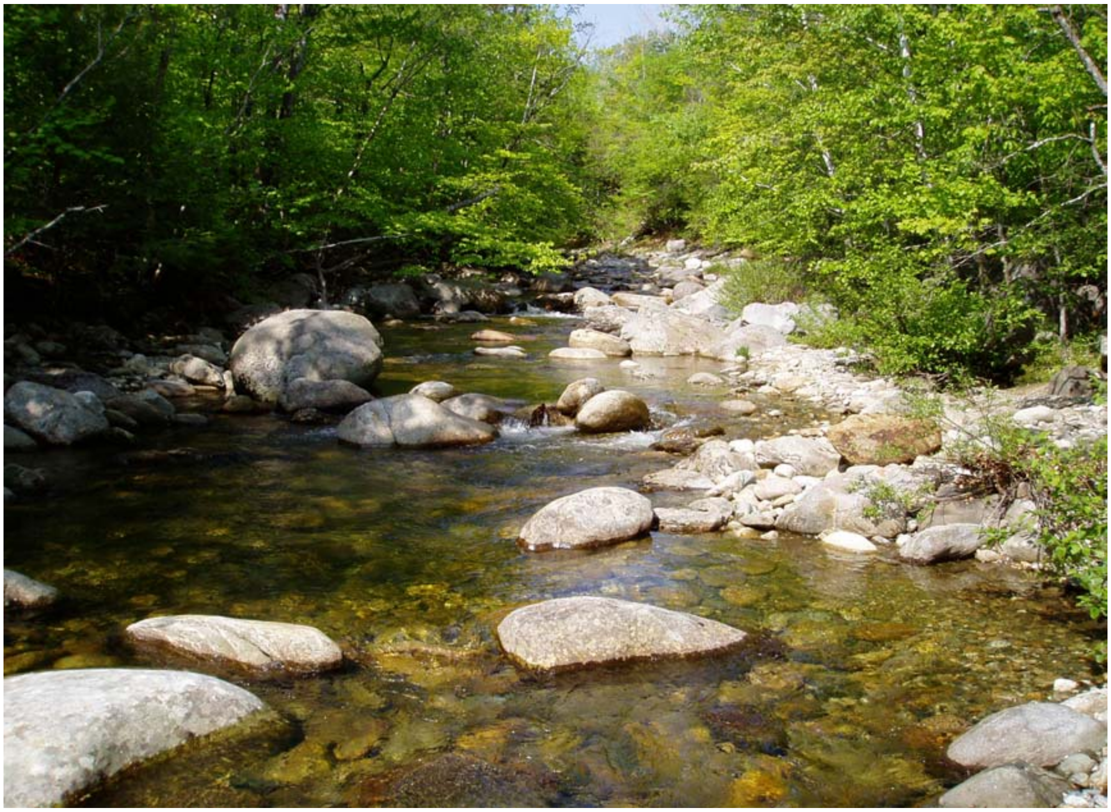
Reach SD-3. Right bank side of monitoring site upstream of covered bridge.

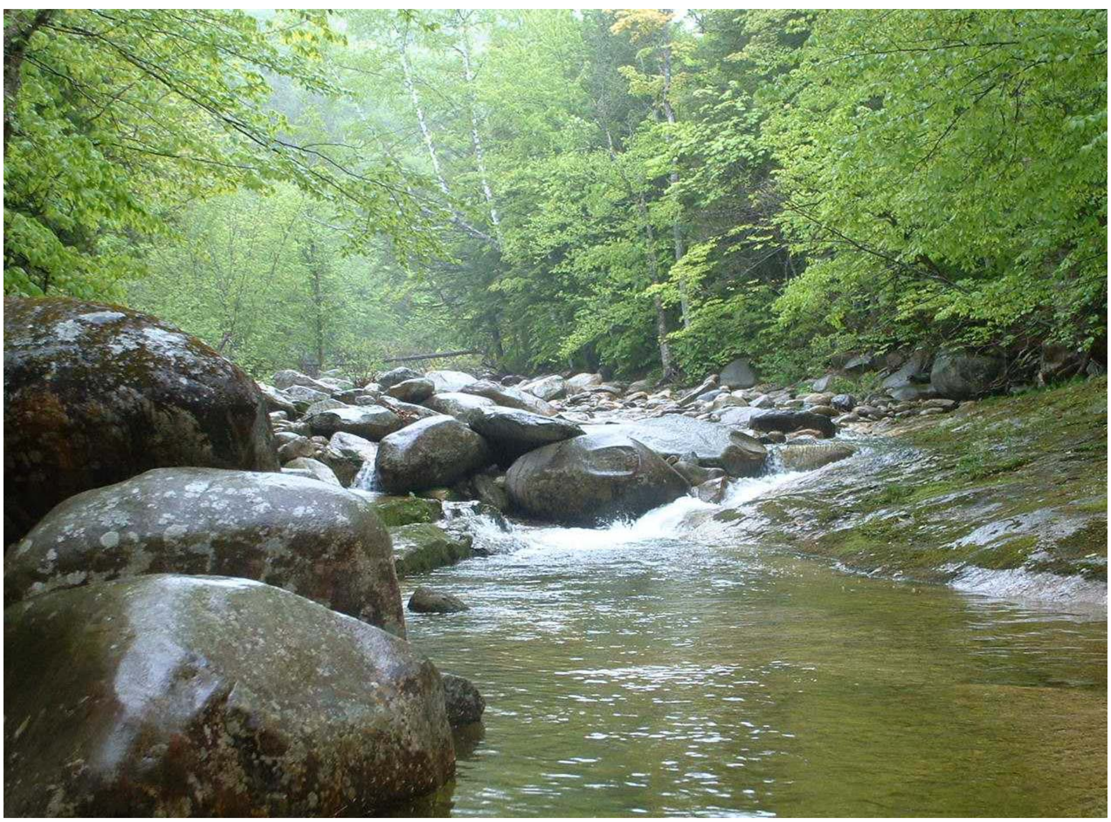
Reach SD-3. Left bank side (high flow channel) of monitoring site upstream of covered bridge.

Reach SD-5. Monitoring site near the Outward Bound property. Note the extensive bank erosion of the downstream left bank.

Reach SD-6. Large scour hole below bedrock outcropping area.

Reach SD-8. Monitoring site located upstream of the ‘gated bridge’.


Reach SD-10. Furthest upstream monitoring station established, note large substrate and overhanging trees.


Reach SD-11. South Branch of the Sunday River. Note the boulders and exposed bedrock.

Reach SD-14. Below confluence of headwater tributaries on the South Branch. Note the major bank erosion and cobble/boulder deposits.

Reach SD-15. Large scarp in headwater tributary. Note large amount of wood debris and clumps of sediment associated with slope failure.

Reach SD-18. Monitoring site on Jordan Brook. Note the larger substrate and steep gradient.

Reach SD-20. Upstream reach of Jordan Brook, note the small size of the channel and dense overhead canopy.

Reach SD-21. Monitoring site on Bull Branch. Note the coarseness of the substrate.

Reach SD-22a. Bedrock knick-point above large scour hole on the Bull Branch.

Reach SD-24. Downstream end of narrowed 'canyon' area. Note large scour hole in foreground of photo.

Reach SD- 28. Downstream reach of Merrill Brook at old timber dam.

Reach SD-30. Upstream reach of Merrill Brook. Observe the extensive bedrock outcroppings.

Reach SD-31. Simons Brook. Note the basal scour of the banks and the moderately dense ground cover in this forested area.

Reach SD-33. Monitoring Site established on Barker's Brook downstream of the Sunday River Road.

Reach SD-34. Barker's Brook upstream of Sunday River Road.

Appendix B

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-1

Location: Main branch of the Sunday River immediately upstream of confluence with the Androscoggin River.
Length surveyed (ft): 1954.55
Number of cross-sections: 6
Date of Survey: August 18, 2003

Controlling Factors

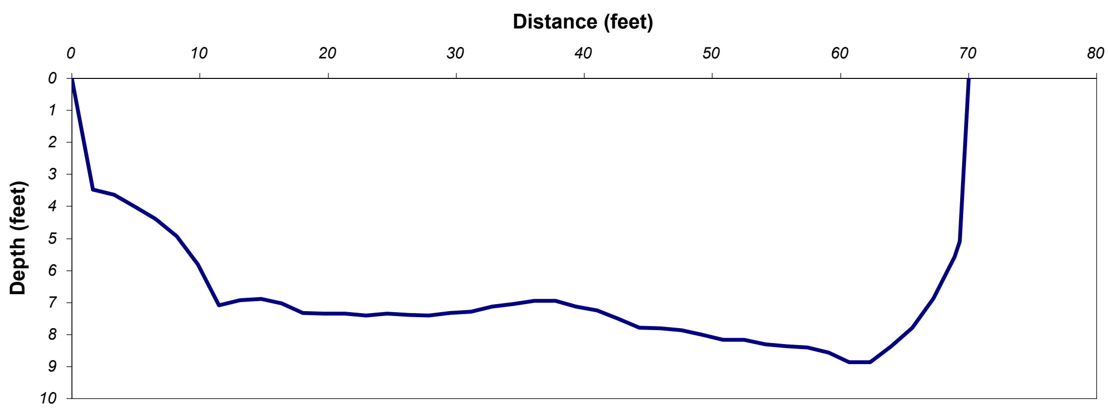
Upstream Drainage Area (mi^2): 51.4
Geology / Soils:

Modifying Factors

Surrounding Land Use: Pasture along the right channel bank and hardwood forest along the left bank.
General Riparian Vegetation: Dec. forest with grasses and herbaceous planst for ground cover
Existing Channel Disturbances: Bank erosion prevelant, some minor debris jams
Woody Debris: Minor to moderate amounts

Cross-Sectional Characteristics	*Metric*		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bankfull Width (m)	18.2 - 31.6	23.1	59.5 - 103.5	75.8	**(ft)**
Bankfull Depth (m)	0.38 - 1.20	0.88	1.3 - 3.9	2.9	**(ft)**
Width / Depth	18.4 - 83.0	32.4	18.4 - 83.0	32.4	
Wetted Width (m)	14.3 - 30.8	19.2	46.9 - 101.0	63.0	**(ft)**
Water Depth (m)	0.15 - 0.71	0.44	0.49 - 2.33	1.4	**(ft)**
Width / Depth	27.3 - 205.3	63.8	27.3 - 205.3	63.8	
Entrenchment (m)	66.6 - 122.4	96.8	218.3 - 401.5	317.6	**(ft)**
Entrenchment Ratio	2.1 - 5.9	4.5	2.1 - 5.9	4.5	

Typical Top of Bank Cross-Section - Site 3



Hydrology

Measured	**Discharge (cfs)**	32-129
Calculated	**Bankfull Flow (cfs)**	726.43
	Bankfull Vel (ft/s)	3.58
Modelled	**2 year flow (cfs)**	N/A

Bank Characteristics

	Metric		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	0.9 - 2.2	1.5	2.9 - 7.2	4.9	**(ft)**
Bank Angle (degrees)	8.5 - 70.0	38.5	8.5 - 70.0	38.5	**Degrees**
Root Depth (cm)	3.0 - 112.0	29.3	1.2 - 44.1	11.5	**(In)**
Root Density ***(1=Low - 5=High)***		3.0		3.0	
Protected by vegetation (%)	0.0 - 90.0	67.5	0.0 - 90.0	67.5	**(%)**
Amount of undercut (cm)	13.0 - 70.0	28.4	5.1 - 27.6	11.2	**(In)**
Banks with undercuts (%)		42%		42%	

Materials	**Torvane Values (kg/cm²)**
* si/vfs	0.13
si/vfs/fs	0.08
si/fs	0.06
si/vfs/fs/cs	0.02
p/vcs/cs	0.01

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	0.085 **%**	
Inter-Pool Gradient	N/A **%**	
Inter-Riffle Gradient	N/A **%**	
Riffle Gradient	N/A **%**	
Riffle Length	N/A **m**	N/A **ft**
Riffle-Pool Spacing	N/A **m**	N/A **ft**
Max Pool Depth	N/A **m**	N/A **ft**

Substrate Characteristics

		Metric		*Imperial*		
Particle Shape (cm)		**Range**	**Average**	**Range**	**Average**	
	X	3.0 - 15.0	8.58	1.18 - 5.91	3.38	**(In)**
	Y	3.0 - 10.0	5.83	1.18 - 3.94	2.30	**(In)**
	Z	1.5 - 7.0	3.50	0.59 - 2.76	1.38	**(In)**

Sub-pavement

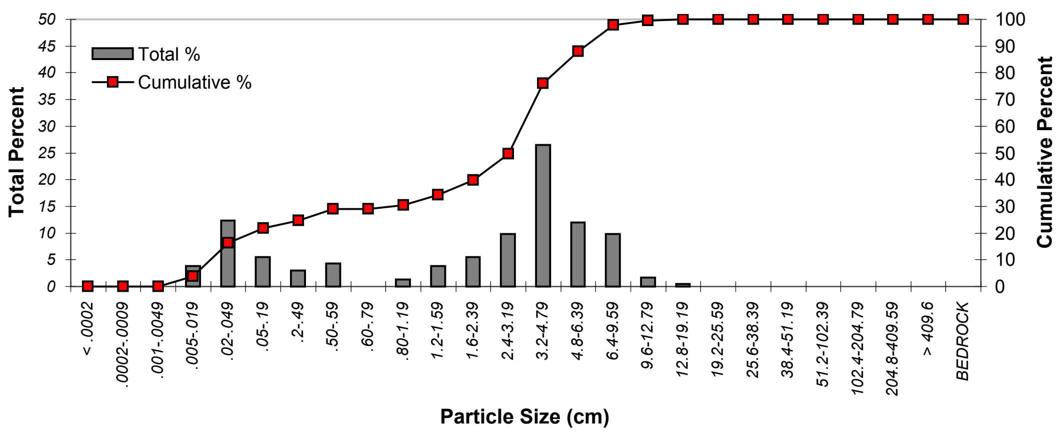
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl	0.0	**P**	20.0
si	0.0	**1 cm**	7.5
vfs	6.3	**1.5cm**	15.0
fs	3.8	**2 cm**	6.3
ms	12.5	**3 cm**	0.0
cs	12.5	**4 cm**	0.0
vcs	16.3	**5 cm**	0.0

Hydraulic Roughness (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	Maximum	5.0 - 50.0	21.5	1.97 - 19.7	8.47	**(In)**
	Median	1.0 - 4.0	2.5	0.39 - 1.58	0.99	**(In)**
	Minimum	0.3 - 0.5	0.3	0.12 - 0.20	0.12	**(In)**
Embeddedness (%)			60%		60%	

Particle Sizes (cm)

	Pebble Counts			
D10	0.02	**cm**	0.01	**(In)**
D50	2.81	**cm**	1.09	**(In)**
D84	5.06	**cm**	1.97	**(In)**
D90	6.08	**cm**	2.37	**(In)**

Substrate Particle Size Distribution Based on Pebble Counts



Field Observations

- Large deposit observed on left bank
- Main flow along right bank near mouth
- Sandy substrate
- Medial bar/island in channel near cross section 3
- Major woody debris in channel

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-2

Location: Main branch of the Sunday River upstream of Barker's Brook confluence
Length surveyed (ft): 3774
Number of cross-sections: 7
Date of Survey: August 19, 2003

Controlling Factors

Upstream Drainage Area (mi^2): 46.7
Geology / Soils:

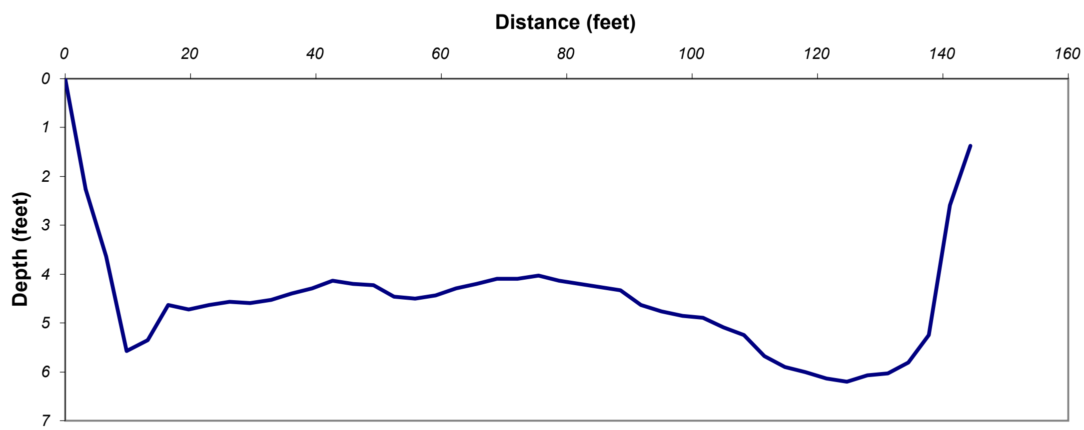
Modifying Factors

Surrounding Land Use: Mainly hardwood forest along both channel banks.
General Riparian Vegetation: Dec. forest with shrub, grass and herbaceous plants in the understory
Existing Channel Disturbances: Upstream portion of Harrington channel avulsion, some bank erosion
Woody Debris: Minor to moderate amounts

Cross-Sectional Characteristics

	Range	Average	Range	Average	
Bankfull Width (m)	20.9 - 43.0	28.9	68.6 - 141.0	94.8	**(ft)**
Bankfull Depth (m)	0.56 - 1.05	0.80	1.8 - 3.4	2.6	**(ft)**
Width / Depth	25.4 - 62.6	37.9	25.4 - 62.6	37.9	
Wetted Width (m)	12.9 - 40.5	22.2	42.3 - 132.9	72.9	**(ft)**
Water Depth (m)	0.24 - 0.59	0.39	0.78 - 1.94	1.3	**(ft)**
Width / Depth	1.4 - 67.3	22.7	1.4 - 67.3	22.7	
Entrenchment (m)	37.6 - 126.7	80.7	123.2 - 415.7	264.6	**(ft)**
Entrenchment Ratio	0.38 - 4.75	1.4	0.38 - 4.75	1.4	

Typical Top of Bank Cross-Section



Hydrology

Measured	**Discharge (cfs)**	32-129
Calculated	**Bankfull Flow (cfs)**	937.26
	Bankfull Vel (ft/s)	3.41
Modelled	**2 year flow (cfs)**	n/a

Bank Characteristics

	Metric		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	0.61 - 1.52	1.10	2.0 - 4.9	3.6	**(ft)**
Bank Angle (degrees)	11.0 - 53.0	34.00	11.0 - 53.0	34.0	**Degrees**
Root Depth (cm)	19.0 - 140.0	81.63	7.41 - 54.6	31.8	**(In)**
Root Density ***(1=Low - 5=High)***	1.0 - 4.0	3.30	1.0 - 4.0	33.0	
Protected by vegetation (%)	10.0 - 95.0	67.20	10.0 - 95.0	67.2	**(%)**
Amount of undercut (cm)	11.0 - 19.0	16.50	4.3 - 7.4	6.4	**(In)**
Banks with undercuts (%)		43%		43%	

Materials	**Torvane Values (kg/cm²)**
* cs/fs	0.06
* s/fs	0.03
* vfs/fs/si	0.03
cs/si	0.01
s/fs/si	0.01

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	0.085 **%**	
Inter-Pool Gradient	N/A **%**	
Inter-Riffle Gradient	N/A **%**	
Riffle Gradient	N/A **%**	
Riffle Length	N/A **m**	N/A **ft**
Riffle-Pool Spacing	N/A **m**	N/A **ft**
Max Pool Depth	N/A **m**	N/A **ft**

Substrate Characteristics

		Metric		*Imperial*		
Particle Shape (cm)		**Range**	**Average**	**Range**	**Average**	
	X	4 - 22	9.8	1.56 - 8.58	3.82	**(In)**
	Y	2.5 - 11	5.72	0.98 - 4.29	2.23	**(In)**
	Z	1 - 9	3.92	0.39 - 3.51	1.53	**(In)**

Sub-pavement

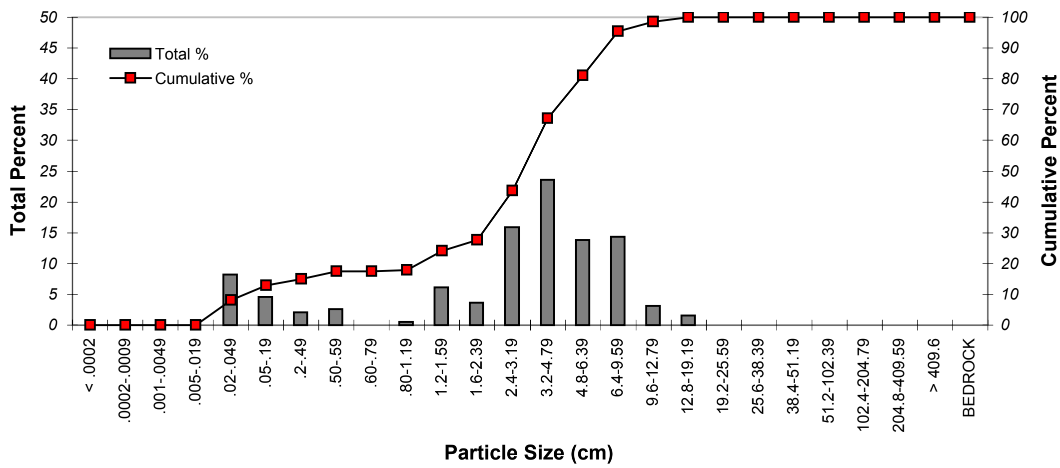
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl	0.0	**P**	29.3
si	0.0	**1 cm**	8.6
vfs	2.9	**1.5cm**	4.3
fs	1.4	**2 cm**	1.4
ms	14.3	**3 cm**	0.0
cs	20.0	**4 cm**	0.0
vcs	17.9	**5 cm**	0.0

Hydraulic Roughness (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	Maximum	9.0 - 70.0	28.67	3.51 - 27.3	11.18	**(In)**
	Median	3.0 - 6.0	4.5	1.17 - 2.34	1.76	**(In)**
	Minimum	0.0 - 0.25	0.25	0.0 - 0.25	0.1	**(In)**
Embeddedness (%)		10 - 50	32%	10 - 50	31.67	

Particle Sizes (cm)

	Pebble Counts	
D10	0.07 **cm**	0.03 **(In)**
D50	3.12 **cm**	1.22 **(In)**
D84	6.09 **cm**	2.38 **(In)**
D90	7.10 **cm**	2.77 **(In)**

Substrate Particle Size Distribution Based on Pebble Counts



Field Observations

- Considerable woody debris in the channel
- Deposition on both channel banks through reach
- Erosion evident on both channel banks through reach

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-3

Location: Main branch of the Sunday River upstream of covered bridge
Length surveyed (ft): 2483
Number of cross-sections: 7
Date of Survey: August 20, 2003

Controlling Factors

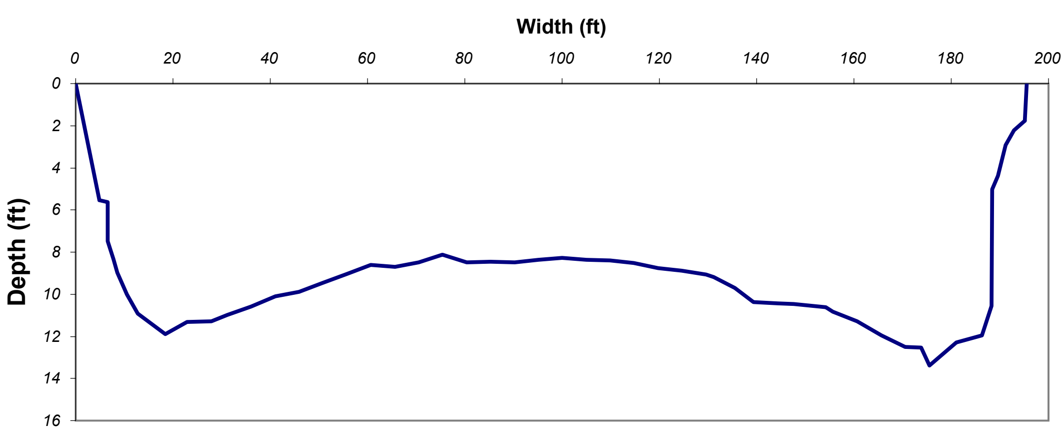
Upstream Drainage Area (mi^2): 41.8

Modifying Factors

Surrounding Land Use: Mainly forest with some recreational trails and limited residential area
General Riparian Vegetation: Dec. forest with some shrub, grass and herbaceous plants in the understory
Existing Channel Disturbances: Covered bridge and road crossing at end of site, occasional debris jams
Woody Debris: Moderate amounts

Cross-Sectional Characteristics	*Metric*		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bankfull Width (m)	26.2 - 54.7	38.5	68.6 - 141.0	126.1	**(ft)**
Bankfull Depth (m)	0.41 - 0.84	0.56	1.8 - 3.4	1.8	**(ft)**
Width / Depth	33.8 - 109.3	71.2	33.8 - 109.3	71.2	
Wetted Width (m)	5.6 - 21.0	9.9	42.3 - 132.9	32.4	**(ft)**
Water Depth (m)	0.11 - 0.54	0.26	0.78 - 1.94	0.9	**(ft)**
Width / Depth	10.4 - 110.7	57.5	10.4 - 110.7	57.5	
Entrenchment (m)	28.8 - 107.5	68.8	123.2 - 415.7	225.7	**(ft)**
Entrenchment Ratio	1.0 - 2.2	1.9	1.0 - 2.2	1.9	

A Typical Top of Bank Cross-section - Site 2



Hydrology

Measured	**Discharge (cfs)**	31 - 45
Calculated	**Bankfull Flow (cfs)**	994.01
	Bankfull Vel (ft/s)	2.77
Modelled	**2 year flow (cfs)**	n/a

Bank Characteristics

	Metric		Imperial		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	0.9 - 2.5	1.6	2.9 - 8.2	5.3	**(ft)**
Bank Angle (degrees)	6.0 - 71.0	30.3	6.0 - 71.0	30.3	**Degrees**
Root Depth (cm)	0.0 - 100.0	18.2	0.0 - 39.4	7.2	**(In)**
Root Density ***(1=Low - 5=High)***	1.0 - 3.0	1.7	1.0 - 3.0	1.7	
Protected by vegetation (%)	0.0 - 50.0	9.1	0.0 - 50.0	9.1	**(%)**
Amount of undercut (cm)	0.0 - 60.0	11.1	0.0 - 23.6	4.4	**(In)**
Banks with undercuts (%)		43%		43%	

Materials	**Torvane Values (kg/cm²)**
cob/p/vcs/cs	0.1
vfs	0.03
sb/cs/vcs/ms	0.1
cob/p/ms/fs	0.1
vfs/fs/si	0.03
cob/p/ms	0.01
p/ms/fs	0.01
fs/ms	0.02
ms	0.03

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	0.44	**%**	
Inter-Pool Gradient	N/A	**%**	
Inter-Riffle Gradient	N/A	**%**	
Riffle Gradient	N/A	**%**	
Riffle Length	N/A	**m**	**ft**
Riffle-Pool Spacing	N/A	**m**	**ft**
Max Pool Depth	N/A	**m**	**ft**

Substrate Characteristics

		Metric		Imperial		
Particle Shape (cm)		**Range**	**Average**	**Range**	**Average**	
	X	2.0 - 32.0	14.5	0.8 - 12.6	5.7	**(In)**
	Y	2.0 - 31.0	10.0	0.8 - 12.2	3.9	**(In)**
	Z	1.5 - 13.0	5.8	0.6 - 5.1	2.3	**(In)**

Sub-pavement

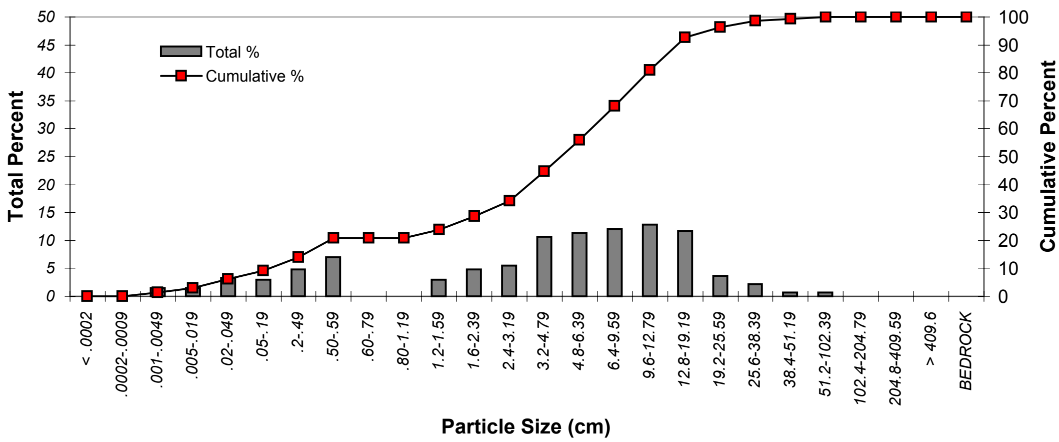
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl	0.0	**P**	13.0
si	0.0	**1 cm**	6.0
vfs	6.0	**1.5cm**	4.0
fs	10.0	**2 cm**	0.0
ms	28.0	**3 cm**	0.0
cs	17.0	**4 cm**	0.0
vcs	16.0	**5 cm**	0.0

Hydraulic Roughness (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	Maximum	8.0 - 60.0	31.8	3.2 - 23.6	12.5	**(In)**
	Median	3.0 - 9.0	5.3	1.18 - 3.54	2.1	**(In)**
	Minimum	0.3 - 2.0	0.6	0.1 - 0.8	0.3	**(In)**
Embeddedness (%)		5.0 - 50.0	28%	5.0 - 50.0	28%	

Particle Sizes (cm)

	Pebble Counts			
D10	0.16	**cm**	0.06	**(In)**
D50	4.74	**cm**	1.87	**(In)**
D84	12.44	**cm**	4.90	**(In)**
D90	14.90	**cm**	5.87	**(In)**

Substrate Particle Size Distribution Based on Pebble Counts



Field Observations

- Large point bar by left bank near cross section 1, directly upstream of bridge.
- Right channel bank is steep, vertical and eroding.
- Woody debris in channel along right bank.
- Path runs along top of right bank.
- Aggradation observed on right bank
- Leaning trees on both banks

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-5

Location:	Main branch of the Sunday River adjacent to Outward Bound
Length surveyed (ft):	1763
Number of cross-sections:	7
Date of Survey:	August 20, 2003

Controlling Factors

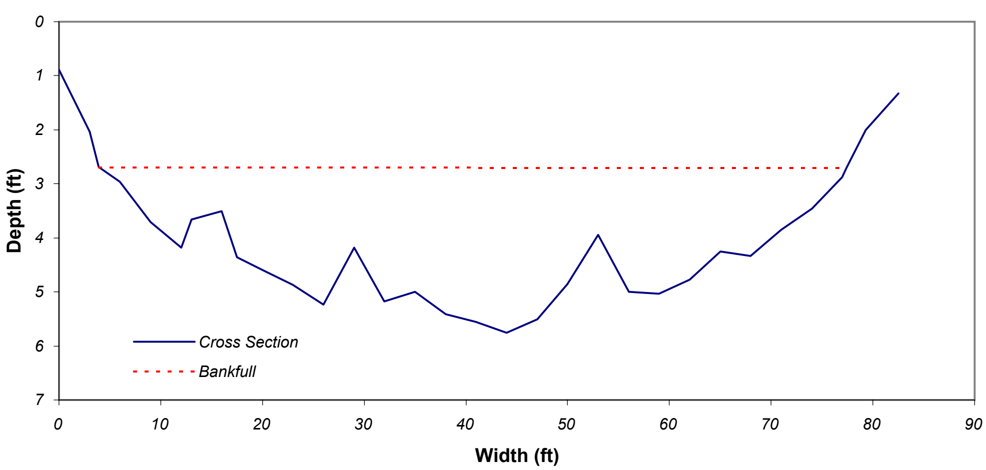
Upstream Drainage Area (mi^2):	37.0
Geology / Soils:	

Modifying Factors

Surrounding Land Use:	Mixed forest, road runs adjecent to channel along site
General Riparian Vegetation:	Trees, shrubs, some herbs and grasses
Existing Channel Disturbances:	Significant bank erosion at roadway
Woody Debris:	Minor amounts in channel

Cross-Sectional Characteristics	*Metric*		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bankfull Width (m)	22.4 - 43.92	35.96	72.82 - 144.06	117.95	**(ft)**
Bankfull Depth (m)	0.50 - 1.13	0.78	1.64 - 3.71	2.56	**(ft)**
Width / Depth	32.43 - 78.26	49.61	32.43 - 78.26	49.61	
Wetted Width (m)	14.94 - 22.19	19.15	49 - 72.78	62.81	**(ft)**
Water Depth (m)	0.19 - 0.50	0.33	0.62 - 1.64	1.08	**(ft)**
Width / Depth	44.46 - 103.56	65.84	44.46 - 103.56	65.84	
Entrenchment (m)	18.29 - 121.92	78.64	60 - 399.90	257.94	**(ft)**
Entrenchment Ratio	0.82 - 3.33	2.09	0.82 - 3.33	2.09	

A Typical Top of Bank Cross-section - Site 4



Hydrology

Measured	**Discharge (cfs)**	31 - 45
Calculated	**Bankfull Flow (cfs)**	994.01
	Bankfull Vel (ft/s)	2.77
Modelled	**2 year flow (cfs)**	n/a

Bank Characteristics

	Metric		Imperial		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	0.9 - 2.5	1.6	2.9 - 8.2	5.3	**(ft)**
Bank Angle (degrees)	6.0 - 71.0	30.3	6.0 - 71.0	30.3	**Degrees**
Root Depth (cm)	0.0 - 100.0	18.2	0.0 - 39.4	7.2	**(In)**
Root Density ***(1=Low - 5=High)***	1.0 - 3.0	1.7	1.0 - 3.0	1.7	
Protected by vegetation (%)	0.0 - 50.0	9.1	0.0 - 50.0	9.1	**(%)**
Amount of undercut (cm)	0.0 - 60.0	11.1	0.0 - 23.6	4.4	**(In)**
Banks with undercuts (%)		43%		43%	

Materials	**Torvane Values (kg/cm²)**
cob/p/vcs/cs	0.1
vfs	0.03
sb/cs/vcs/ms	0.1
cob/p/ms/fs	0.1
vfs/fs/si	0.03
cob/p/ms	0.01
p/ms/fs	0.01
fs/ms	0.02
ms	0.03

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	0.70 **%**	
Inter-Pool Gradient	N/A **%**	
Inter-Riffle Gradient	N/A **%**	
Riffle Gradient	N/A **%**	
Riffle Length	N/A **m**	N/A **ft**
Riffle-Pool Spacing	N/A **m**	N/A **ft**
Max Pool Depth	N/A **m**	N/A **ft**

Substrate Characteristics

Particle Shape (cm)	Metric		Imperial		
	Range	**Average**	**Range**	**Average**	
X	11.4 - 38.1	23.6	4.5 - 15.0	9.3	**(In)**
Y	7.6 - 25.4	16.9	3.0 - 10.0	6.7	**(In)**
Z	5.1 - 20.3	11.1	2.0 - 8.0	4.4	**(In)**

Sub-pavement

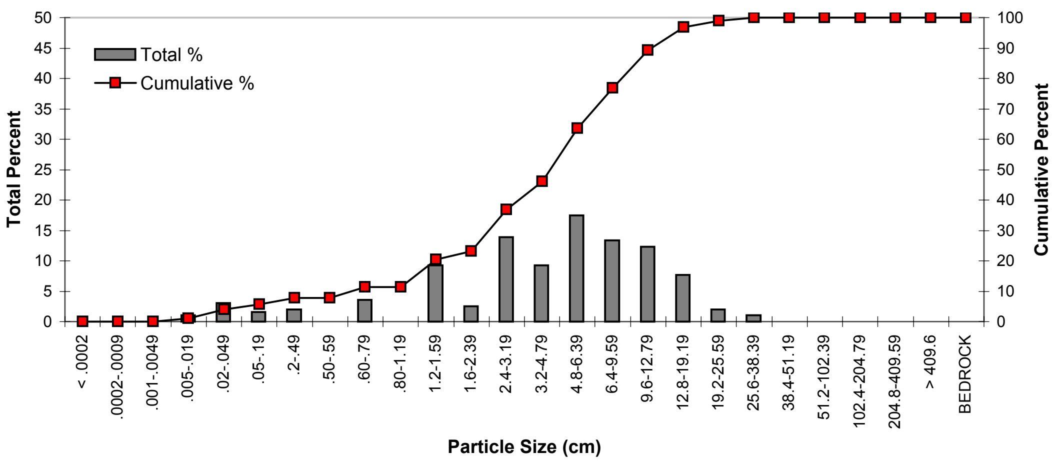
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl	0.0	**P**	13.0
si	0.0	**1 cm**	6.0
vfs	6.0	**1.5cm**	4.0
fs	10.0	**2 cm**	0.0
ms	28.0	**3 cm**	0.0
cs	17.0	**4 cm**	0.0
vcs	16.0	**5 cm**	0.0

Hydraulic Roughness (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	Maximum	35.6 - 81.3	50.8	14.0 - 32.0	20.0	**(In)**
	Median	12.7 - 25.4	16.3	5.0 - 10.0	6.4	**(In)**
	Minimum	0.2 - 1.3	0.5	0.1 - 0.5	0.2	**(In)**
Embeddedness (%)		0.0 - 45.0	15%	0.0 - 45.0	15%	

Particle Sizes (cm)

	Pebble Counts			
D10	0.16	**cm**	0.06	**(In)**
D50	4.67	**cm**	1.84	**(In)**
D84	15.90	**cm**	6.26	**(In)**
D90	23.10	**cm**	9.09	**(In)**

Substrate Particle Size Distribution Based on Pebble Counts



Field Observations

- right bank tends to be relatively low-lying floodplain
- right bank has a point bar
- right bank has signs of recent sand deposits
- major undercut along left bank (roadway) with large amounts of exposed tree roots
- channel relatively straight with only subtle bedform

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-10

Location:	South branch of the Sunday River
Length surveyed (ft):	2054
Number of cross-sections:	6
Date of Survey:	August 19, 2003

Controlling Factors

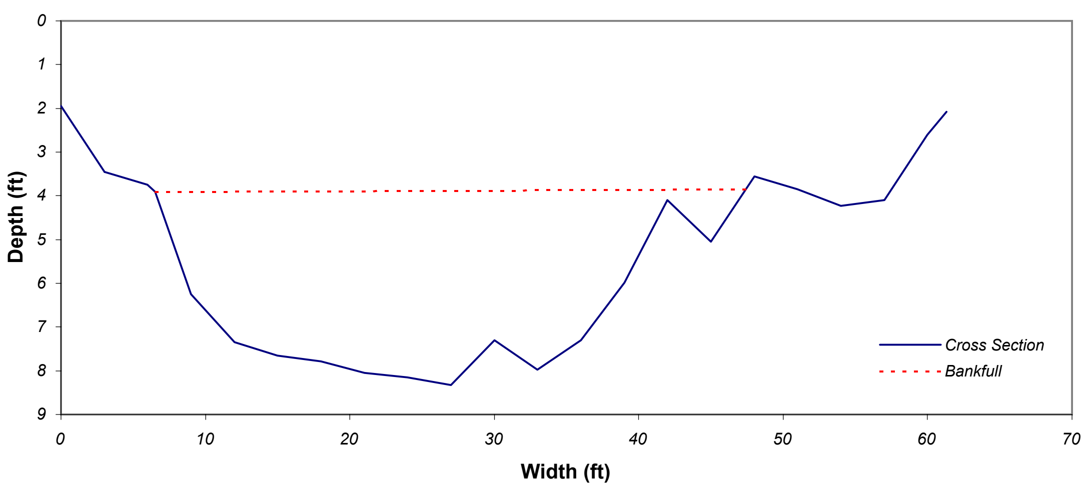
Upstream Drainage Area (mi^2):	< 11.6
Geology / Soils:	

Modifying Factors

Surrounding Land Use:	Mixed forest with discontinued logging trails
General Riparian Vegetation:	Trees, shrubs, some herbs and grasses
Existing Channel Disturbances:	Several debris jams, washed out roadway
Woody Debris:	Minor amounts in channel

Cross-Sectional Characteristics	*Metric*		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bankfull Width (m)	9.5 - 21.9	14.7	31.0 - 72.0	48.1	**(ft)**
Bankfull Depth (m)	0.37 - 1.08	0.67	1.2 - 3.54	2.2	**(ft)**
Width / Depth	8.8 - 51.7	25.6	8.8 - 51.7	25.6	
Wetted Width (m)	6.4 - 12.6	10.1	21.0 - 41.3	33.2	**(ft)**
Water Depth (m)	0.16 - 0.45	0.26	0.50 - 1.48	0.85	**(ft)**
Width / Depth	22.0 - 75.0	44.6	22.0 - 75.0	44.6	
Entrenchment (m)	51.1 - 58.3	53.5	51.1 - 58.3	53.5	**(ft)**
Entrenchment Ratio	3.2 - 3.9	3.5	3.2 - 3.9	3.5	

A Typical Top of Bank Cross Section - Site 3



Hydrology

Measured	**Discharge (cfs)**	N/A
Calculated	**Bankfull Flow (cfs)**	N/A
	Bankfull Vel (ft/s)	N/A
Modelled	**2 year flow (cfs)**	N/A

Bank Characteristics

	Metric		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	1.6 - 3.5	2.5	5.3 - 11.5	8.3	**(ft)**
Bank Angle (degrees)	30.0 - 90.0	46.3	30 - 90	46.3	**Degrees**
Root Depth (cm)	5.0 - 46.0	20.2	2.0 - 18.1	8.0	**(In)**
Root Density ***(1=Low - 5=High)***	1.0 - 3.0	1.4	1.0 - 3.0	1.4	
Protected by vegetation (%)	0.0 - 60.0	19.2	0 - 60	19.2	**(%)**
Amount of undercut (cm)	0.0 - 0.0	0	0.0 - 0.0	0.0	**(In)**
Banks with undercuts (%)		0%			

Materials **Torvane Values (kg/cm²)**

Not Available

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	2.38 **%**	
Inter-Pool Gradient	N/A **%**	
Inter-Riffle Gradient	N/A **%**	
Riffle Gradient	N/A **%**	
Riffle Length	N/A **m**	N/A **ft**
Riffle-Pool Spacing	N/A **m**	N/A **ft**
Max Pool Depth	N/A **m**	N/A **ft**

Substrate Characteristics

		Metric		*Imperial*		
Particle Shape (cm)		**Range**	**Average**	**Range**	**Average**	
	X	6.5 - 40	20.0	2.56 - 15.7	7.9	**(In)**
	Y	5.5 - 20	12.9	2.17 - 7.87	5.1	**(In)**
	Z	2.5 - 14.5	7.6	0.98 - 5.71	3.0	**(In)**

Sub-pavement

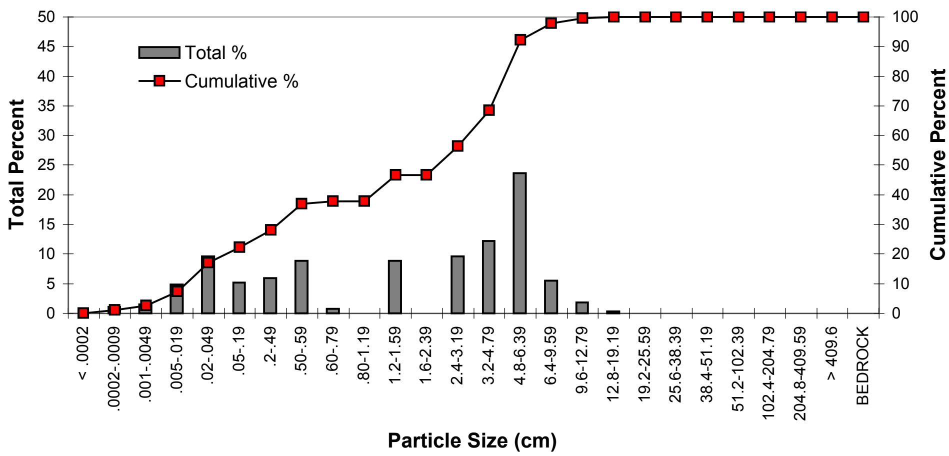
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl		**P**	
si		**1 cm**	
vfs		**1.5cm**	
fs	Not Available	**2 cm**	
ms		**3 cm**	
cs		**4 cm**	
vcs		**5 cm**	

Hydraulic Roughness (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	Maximum	40.0 - 87.0	64.2	15.74 - 34.25	25.26	**(In)**
	Median	4.0 - 11.0	6.8	1.57 - 4.33	2.66	**(In)**
	Minimum	0.3 - 3.0	0.9	0.10 - 1.18	0.36	**(In)**
Embeddedness (%)		0.0 - 5.0	4.2	0.0 - 5.0	4.2	

Particle Sizes (cm)

	Pebble Counts			
D10	1.40	**cm**	0.55	**(In)**
D50	11.30	**cm**	4.45	**(In)**
D84	24.96	**cm**	9.83	**(In)**
D90	30.17	**cm**	11.88	**(In)**

Substrate Particle Size Distribution Based on Pebble Counts



Field Observations

- lots of trees near the river's edge
- washed out road along right bank
- right bank has fallen and leaning trees
- left bank is eroded with tree roots exposed
- right bank eroded in downsteam section
- secondary channel along left bank

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-18

Location: Downstream portion of Jordan Brook
Length surveyed (ft): 596
Number of cross-sections: 6
Date of Survey: August 21, 2003

Controlling Factors

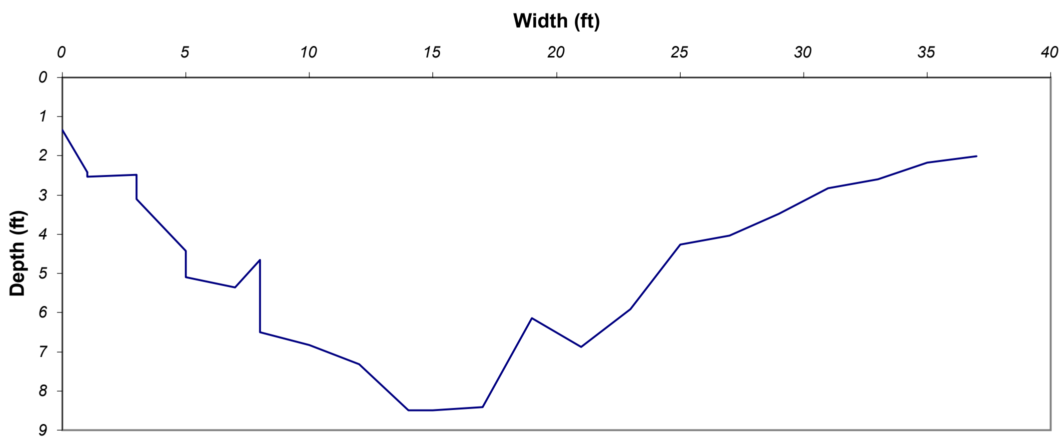
Upstream Drainage Area (mi^2): 2.3
Geology / Soils:

Modifying Factors

Surrounding Land Use: Mixed forest
General Riparian Vegetation: Trees, shrubs, some herbaceous understory
Existing Channel Disturbances: Trail crossing near confluence with Sunday River
Woody Debris: Minor

Cross-Sectional Characteristics	*Metric*		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bankfull Width (m)	6.96 - 10.49	8.7	22.83 - 34.41	28.6	**(ft)**
Bankfull Depth (m)	0.3 - 0.83	0.5	0.98 - 2.72	1.7	**(ft)**
Width / Depth	10.04 - 26.55	18.5	10.04 - 26.55	18.5	
Wetted Width (m)	4.62 - 7.44	6.2	15.15 - 24.40	20.2	**(ft)**
Water Depth (m)	0.04 - 0.48	0.2	0.13 - 1.57	0.5	**(ft)**
Width / Depth	11.49 - 181.74	76.5	11.49 - 181.74	76.5	
Entrenchment (m)	8 - 41	23.5	26.24 - 134.48	77.1	**(ft)**
Entrenchment Ratio	0.86 - 5.08	2.8	0.86 - 5.08	2.8	

A Typical Top of Bank Cross-section - Site 6



Hydrology

Measured	**Discharge (cfs)**	N/A
Calculated	**Bankfull Flow (cfs)**	N/A
	Bankfull Vel (ft/s)	N/A
Modelled	**2 year flow (cfs)**	N/A

Bank Characteristics

	Metric		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	0.5 - 20.0	3.0	1.64 - 65.6	9.84	**(ft)**
Bank Angle (degrees)		N/A		N/A	**Degrees**
Root Depth (cm)	5.0 - 110.0	49.4	1.9 - 43.0	19.5	**(In)**
Root Density ***(1=Low - 5=High)***	1.0 - 4.0	2.5	1.0 - 4.0	2.5	
Protected by vegetation (%)	0.0 - 90.0	24.2	0 - 90	24.2	**(%)**
Amount of undercut (cm)	13.0 - 91.5	50.9	5.1 - 36.0	20.0	**(In)**
Banks with undercuts (%)		50%		50%	

Materials **Torvane Values (kg/cm^2)**

Not Available

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	5.42 **%**	
Inter-Pool Gradient	N/A **%**	
Inter-Riffle Gradient	N/A **%**	
Riffle Gradient	N/A **%**	
Riffle Length	N/A **m**	N/A **ft**
Riffle-Pool Spacing	N/A **m**	N/A **ft**
Max Pool Depth	N/A **m**	N/A **ft**

Substrate Characteristics

Particle Shape (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	X	10.0 - 66.0	26.9	3.94 - 25.98	10.6	**(In)**
	Y	10.0 - 51.0	18.8	3.94 - 20.08	7.4	**(In)**
	Z	4.0 - 20.0	11.3	1.57 - 7.87	4.5	**(In)**

Sub-pavement

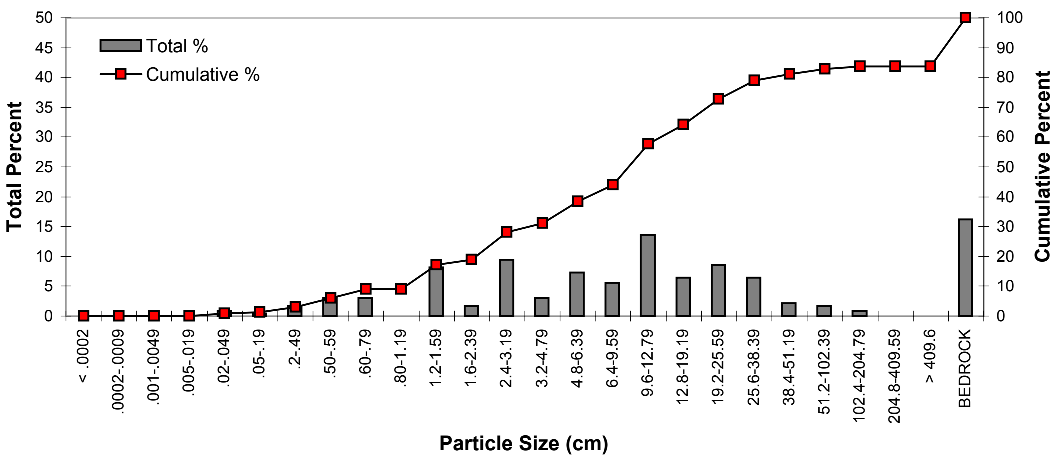
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl	0.0	**P**	19.0
si	1.0	**1 cm**	16.0
vfs	0.0	**1.5cm**	0.0
fs	0.0	**2 cm**	9.0
ms	0.0	**3 cm**	4.0
cs	3.0	**4 cm**	0.0
vcs	8.0	**5 cm**	0.0
		Bedrock	40.0

Hydraulic Roughness (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	Maximum	18 - 71	38.8	7.09 - 27.95	15.3	**(In)**
	Median	10 - 25	17.5	3.94 - 9.84	6.9	**(In)**
	Minimum	0 - 0.5	0.3	0 - 0.20	0.1	**(In)**
Embeddedness (%)		0 - 10	5.8	0 - 3.94	2.3	

Particle Sizes (cm)

	Pebble Counts			
D10	0.665	**cm**	0.26	**(In)**
D50	7.072	**cm**	2.78	**(In)**
D84	20.68	**cm**	8.14	**(In)**
D90	26.49	**cm**	10.43	**(In)**

Substrate Particle Size Distribution Based on Pebble Counts



Field Observations

Site 1 has exposed bedrock by the right bank that is covered in moss.
Site 2 has a steeper right bank than left bank. It is the monitoring site.
Site 3 has very large boulders in the channel and is approximately 1 metre upstream from a drop.
Site 4 has heavy undercutting on the right bank.
Site 5 has minor undercutting on the right bank.
Site 6 is a pool area, with the right bank being a valley wall and exposed tree roots on the left bank.

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-21

Location:	Downstream reach of Bull Branch
Length surveyed (ft):	996
Number of cross-sections:	6
Date of Survey:	August 18, 2003

Controlling Factors

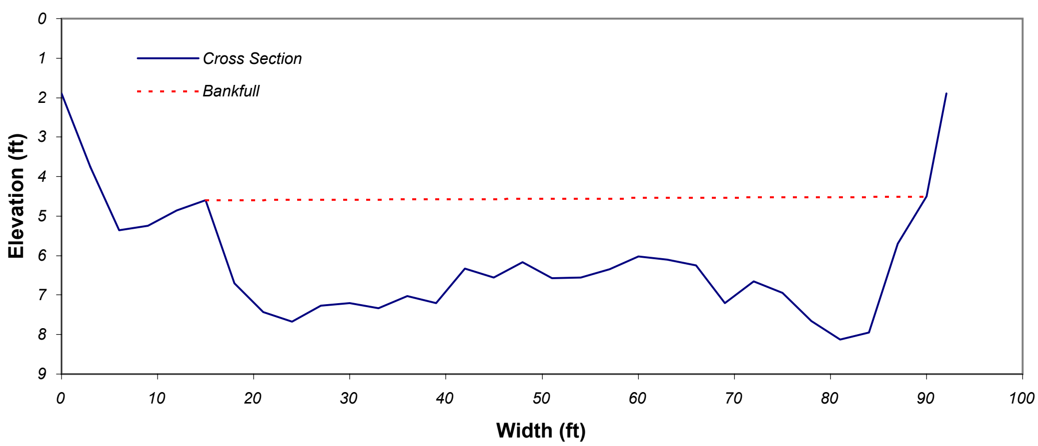
Upstream Drainage Area (mi^2):	17.4
Geology / Soils:	

Modifying Factors

Surrounding Land Use:	Mixed forest with nearby logging trails and a private drive
General Riparian Vegetation:	Trees, shrubs, some herbaceous understory incl mosses
Existing Channel Disturbances:	Twin bridges crossing at downstream end of reach
Woody Debris:	Minor amounts

Cross-Sectional Characteristics	*Metric*		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bankfull Width (m)	9.45 - 21.95	14.7	31 - 72	48.1	**(ft)**
Bankfull Depth (m)	0.37 - 1.08	0.7	1.21 - 3.54	2.2	**(ft)**
Width / Depth	8.75 - 51.73	25.6	8.75 - 51.73	25.6	
Wetted Width (m)	6.4 - 12.59	10.1	20.99 - 41.30	33.2	**(ft)**
Water Depth (m)	0.16 - 0.45	0.3	0.5 - 1.48	0.9	**(ft)**
Width / Depth	22.01 - 74.96	44.6	22.01 - 74.96	44.6	
Entrenchment (m)	50 - 60	56.7	164 - 196.8	185.9	**(ft)**
Entrenchment Ratio	0 - 6.35	2.7	0 - 6.35	2.7	

A Typical Top of Bank Cross-section- Site 4



Hydrology

Measured	**Discharge (cfs)**	N/A
Calculated	**Bankfull Flow (cfs)**	N/A
	Bankfull Vel (ft/s)	N/A
Modelled	**2 year flow (cfs)**	N/A

Bank Characteristics

	Metric		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	0.35 - 1.98	1.3	1.15 - 6.49	4.3	**(ft)**
Bank Angle (degrees)	30.0 - 90.0	58.8	30 - 90	58.8	**Degrees**
Root Depth (cm)	0.61 - 200.0	53.7	24.0 - 78.7	21.1	**(In)**
Root Density ***(1=Low - 5=High)***	1.0 - 3.0	2.1	1 - 3	2.1	
Protected by vegetation (%)	0.0 - 90.0	47.5	0 - 90	47.5	**(%)**
Amount of undercut (cm)	5.0 - 55.0	34.3	2.0 - 21.7	13.5	**(In)**
Banks with undercuts (%)		25%		25%	

Materials **Torvane Values (kg/cm²)**

Not Available

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	1.44 **%**	
Inter-Pool Gradient	N/A **%**	
Inter-Riffle Gradient	N/A **%**	
Riffle Gradient	N/A **%**	
Riffle Length	N/A **m**	N/A **ft**
Riffle-Pool Spacing	N/A **m**	N/A **ft**
Max Pool Depth	N/A **m**	N/A **ft**

Substrate Characteristics

Particle Shape (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	X	13 - 44	22.9	5.11 - 17.32	9.0	**(In)**
	Y	8 - 28	15.9	3.15 - 11.02	9.3	**(In)**
	Z	5.5 - 15	8.5	2.16 - 5.91	3.4	**(In)**

Sub-pavement

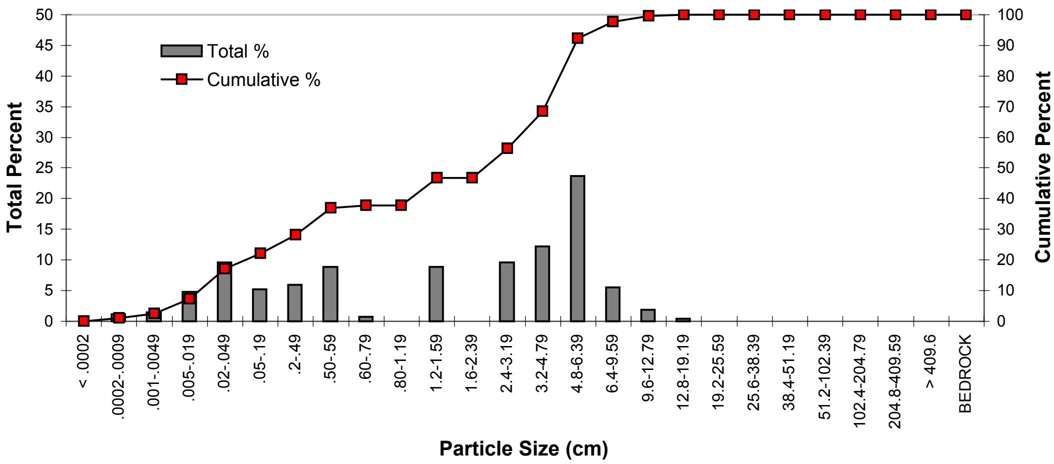
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl		**P**	
si		**1 cm**	
vfs		**1.5cm**	
fs	Not Available	**2 cm**	
ms		**3 cm**	
cs		**4 cm**	
vcs		**5 cm**	
		Bedrock	

Hydraulic Roughness (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	Maximum	45 - 69	58.0	17.72 - 27.17	22.8	**(In)**
	Median	5 - 41	26.2	1.97 - 16.14	10.3	**(In)**
	Minimum	1 - 7	3.0	0.39 - 2.76	1.2	**(In)**
Embeddedness (%)			0%		0%	

Particle Sizes (cm)

	Pebble Counts			
D10	1.395	**cm**	0.55	**(In)**
D50	11.3	**cm**	4.45	**(In)**
D84	24.96	**cm**	9.83	**(In)**
D90	30.17	**cm**	11.88	**(In)**

Substrate Particle Size Distribution Based on Pebble Counts



Field Observations

- coarse substrate, mainly cobble and small boulders
- banks relatively low and moderately vegetated
- site adjacent to roadway
- bedforms generally subtle
- wood debris generally sparse

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-28

Location:	Downstream reach of Merrill Brook
Length surveyed (ft):	731
Number of cross-sections:	7
Date of Survey:	August 18, 2003

Controlling Factors

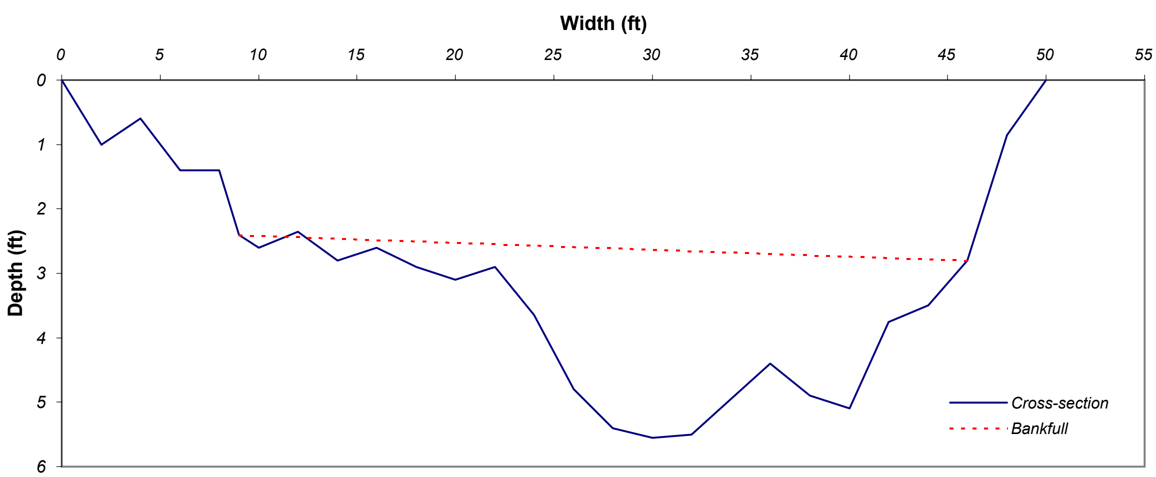
Upstream Drainage Area (mi^2): 2.3

Modifying Factors

Surrounding Land Use:	Natural valley with a golf course on tablelands
General Riparian Vegetation:	Birch, hemlock, maple, shrubs, herb and grass
Existing Channel Disturbances:	Some erosion
Woody Debris:	Minor to moderate amounts

Cross-Sectional Characteristics	*Metric*		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bankfull Width (m)	9.86 - 16.32	11.9	32.35 - 53.54	39.1	**(ft)**
Bankfull Depth (m)	0.25 - 0.98	0.5	0.82 - 3.22	1.7	**(ft)**
Width / Depth	11.55 - 44.26	27.1	11.55 - 44.26	27.1	
Wetted Width (m)	3.35 - 14.31	7.5	10.99 - 46.95	24.7	**(ft)**
Water Depth (m)	0.1 - 0.57	0.3	0.33 - 1.87	1.0	**(ft)**
Width / Depth	9.42 - 55.45	32.8	9.42 - 55.45	32.8	
Entrenchment (m)	31.2 - 60	43.5	102.36 - 196.85	142.7	**(ft)**
Entrenchment Ratio	2.57 - 5.41	3.7	2.57 - 5.41	3.7	

A Typical Top of Bank Cross-section - Site 1



Hydrology

Measured	**Discharge (cfs)**	N/A
Calculated	**Bankfull Flow (cfs)**	N/A
	Bankfull Vel (ft/s)	N/A
Modelled	**2 year flow (cfs)**	N/A

Bank Characteristics

	Metric		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	1 - 10	2.9	3.28 - 32.81	9.5	**(ft)**
Bank Angle (degrees)	15 - 90	33.8	15 - 90	33.8	**Degrees**
Root Depth (cm)	30 - 140	66.7	0.98 - 4.59	26.3	**(In)**
Root Density ***(1=Low - 5=High)***		N/A		N/A	
Protected by vegetation (%)	10 - 70	33.2	10 - 70	33.2	**(%)**
Amount of undercut (cm)	5 - 122	51.4	0.16 - 4.00	20.2	**(In)**
Banks with undercuts (%)		57%		57%	

Materials **Torvane Values (kg/cm²)**

Not Available

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	6.17	**%**		
Inter-Pool Gradient	N/A	**%**		
Inter-Riffle Gradient	N/A	**%**		
Riffle Gradient	N/A	**%**		
Riffle Length	N/A	**m**	N/A	**ft**
Riffle-Pool Spacing	N/A	**m**	N/A	**ft**
Max Pool Depth	N/A	**m**	N/A	**ft**

Substrate Characteristics

		Metric		*Imperial*		
Particle Shape (cm)		**Range**	**Average**	**Range**	**Average**	
	X	9 - 71	26.07	3.54 - 27.95	10.26	**(In)**
	Y	9 - 43	19.19	3.54 - 16.93	7.56	**(In)**
	Z	4 - 33	11.19	1.57 - 12.99	4.41	**(In)**

Sub-pavement

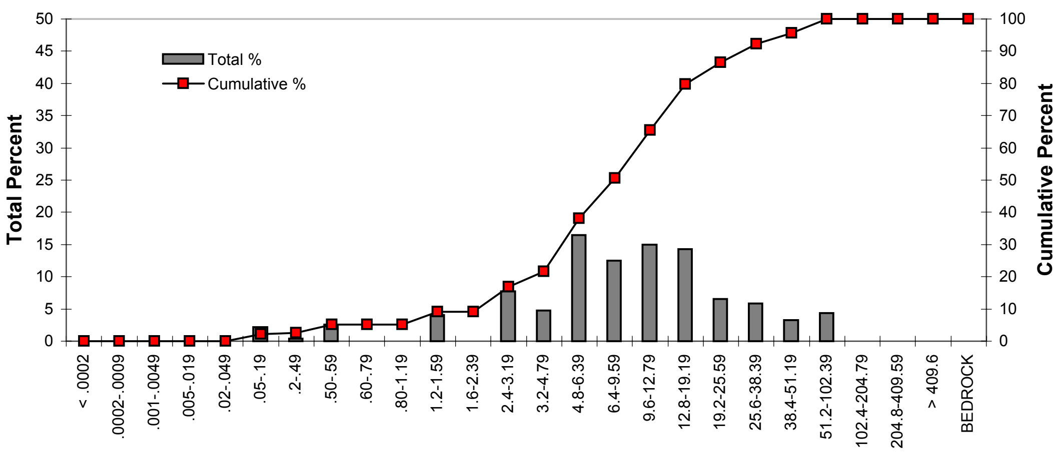
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl	0.0	**P**	22.1
si	0.7	**1 cm**	30.7
vfs	5.7	**1.5cm**	2.1
fs	0.0	**2 cm**	12.9
ms	2.1	**3 cm**	12.9
cs	0.0	**4 cm**	0.0
vcs	10.7	**5 cm**	0.0
		Bedrock	

		Metric		*Imperial*		
Hydraulic Roughness (cm)		**Range**	**Average**	**Range**	**Average**	
	Maximum	15 - 137	89.86	5.91 - 53.94	35.38	**(In)**
	Median	5 - 38	23.2	1.97 - 14.96	9.13	**(In)**
	Minimum	0.5 - 2.54	1.51	0.20 - 1	0.59	**(In)**
Embeddedness (%)		10 - 30	15.71	10 - 30	15.71	

Particle Sizes (cm)

	Pebble Counts	
D10	N/A **cm**	N/A **(In)**
D50	N/A **cm**	N/A **(In)**
D84	N/A **cm**	N/A **(In)**

Substrate Particle Size Distribution Based on Pebble Counts



Field Observations

Site 1 has a steep right bank with a large undercut.
Site 2 is a pool area with a large undercut on right bank.
Site 3 is just upstream from where the gradient begins to decrease.
Site 4 has boulders and cobbles high in the bank that supply the creek with the large rocks.
Site 5 has a mid channel bar.
Site 6 has a mid channel bar with cobbles and boulders.
Site 7 is downstream of a culvert and contains a large amount of boulders.

FLUVIAL GEOMORPHOLOGY SUMMARY

Sunday River Reach SD-33

Location:	Downstream reach of Barker's Brook
Length surveyed (ft):	1325
Number of cross-sections:	7
Date of Survey:	August 19, 2003

Controlling Factors

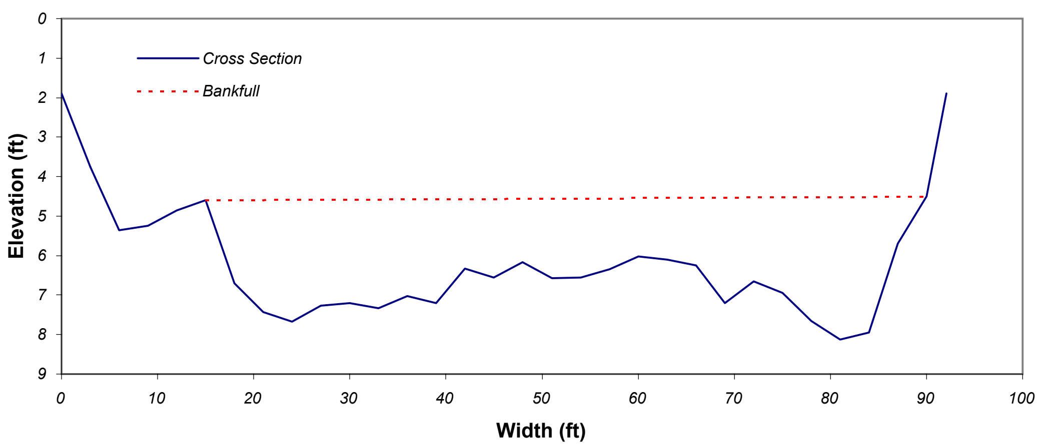
Upstream Drainage Area (mi^2): 3.4

Modifying Factors

Surrounding Land Use:	Natural valley on floodplain of Sunday River
General Riparian Vegetation:	Alders, sumac, birch, herbs and grasses
Existing Channel Disturbances:	Sunday River Road crossing upstream of site
Woody Debris:	Minor amounts

Cross-Sectional Characteristics	*Metric*		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bankfull Width (m)	4.53 - 16.67	8.19	14.86 - 54.68	26.86	**(ft)**
Bankfull Depth (m)	0.24 - 0.67	0.53	0.79 - 2.20	1.74	**(ft)**
Width / Depth	9.95 - 41.95	17.53	9.95 - 41.95	17.53	
Wetted Width (m)	2.77 - 6.73	4.54	9.09 - 22.07	14.89	**(ft)**
Water Depth (m)	0.09 - 0.31	0.19	0.29 - 1.02	0.62	**(ft)**
Width / Depth	14.48 - 76.42	29.61	14.48 - 76.42	29.61	
Entrenchment (m)	10.67 - 60.96	53.78	35 - 200	176.4	**(ft)**
Entrenchment Ratio	2.06 - 13.46	7.38	2.06 - 13.46	7.38	

A Typical Top of Bank Cross-section- Site 4



Hydrology

Measured	**Discharge (cfs)**	N/A
Calculated	**Bankfull Flow (cfs)**	N/A
	Bankfull Vel (ft/s)	N/A
Modelled	**2 year flow (cfs)**	N/A

Bank Characteristics

	Metric		*Imperial*		
	Range	**Average**	**Range**	**Average**	
Bank Height (m)	0.7 - 2	1.3	2.3 - 6.56	4.3	**(ft)**
Bank Angle (degrees)	30 - 90	55.9	30 - 90	55.9	**Degrees**
Root Depth (cm)	10 - 75	47.7	32.8 - 246	156.5	**(In)**
Root Density ***(1=Low - 5=High)***	2 - 4	2.7	2 - 4	2.7	
Protected by vegetation (%)	5 - 60	28.9	5 - 60	28.9	**(%)**
Amount of undercut (cm)	15 - 75	27.2	49.2 - 246	89.2	**(In)**
Banks with undercuts (%)		71%		71%	

Materials **Torvane Values (kg/cm²)**

Not Available

* = dominant material

Planform Characteristics

Long Profile (avg)

Bankfull Gradient	0.19 **%**	
Inter-Pool Gradient	N/A **%**	
Inter-Riffle Gradient	N/A **%**	
Riffle Gradient	N/A **%**	
Riffle Length	N/A **m**	N/A **ft**
Riffle-Pool Spacing	N/A **m**	N/A **ft**
Max Pool Depth	N/A **m**	N/A **ft**

Substrate Characteristics

Particle Shape (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	X	2.54 - 19.05	8.6	1 - 7.5	3.4	**(In)**
	Y	2.54 - 11.43	6.4	1 - 4.5	2.5	**(In)**
	Z	0.64 - 6.55	4.2	0.25 - 2.6	1.7	**(In)**

Sub-pavement

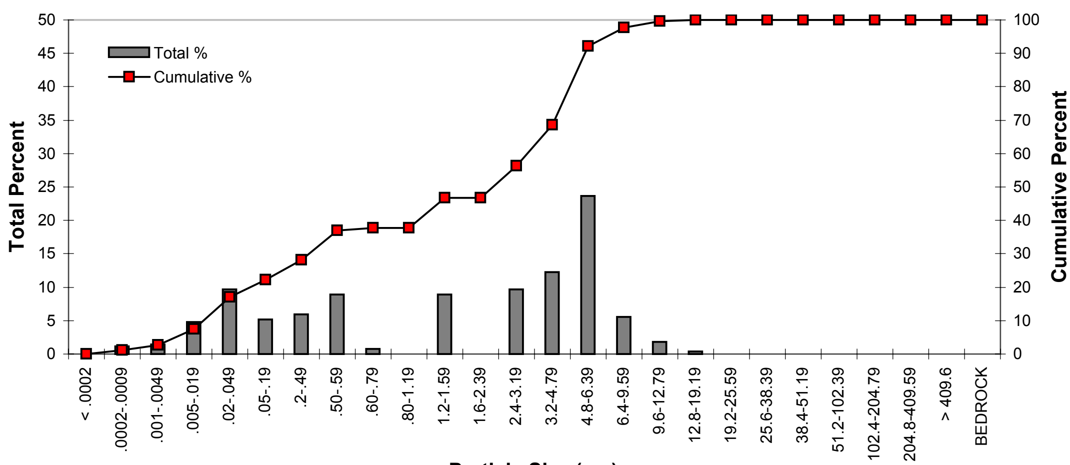
Part. Size	**% of subpavement on site**	**Part. Size**	**% of subpavement on site**
cl	0.0	**P**	21.7
si	0.0	**1 cm**	15.0
vfs	0.0	**1.5cm**	15.0
fs	1.7	**2 cm**	0.0
ms	10.0	**3 cm**	8.3
cs	5.8	**4 cm**	0.0
vcs	10.0	**5 cm**	8.3
		Bedrock	4.2

Hydraulic Roughness (cm)		*Metric*		*Imperial*		
		Range	**Average**	**Range**	**Average**	
	Maximum	5.08 - 83.82	20.3	2 - 33	8.0	**(In)**
	Median	0.05 - 7.62	2.9	0.02 - 3	1.1	**(In)**
	Minimum	0 - 0.02	0.0	0 - 0.01	0.0	**(In)**
Embeddedness (%)		40 - 100	78.6	40 - 100	78.6	

Particle Sizes (cm)

	Pebble Counts			
D10	0.0181	**cm**	0.01	**(In)**
D50	2.272	**cm**	0.89	**(In)**
D84	5.04	**cm**	1.98	**(In)**

Substrate Particle Size Distribution Based on Pebble Counts

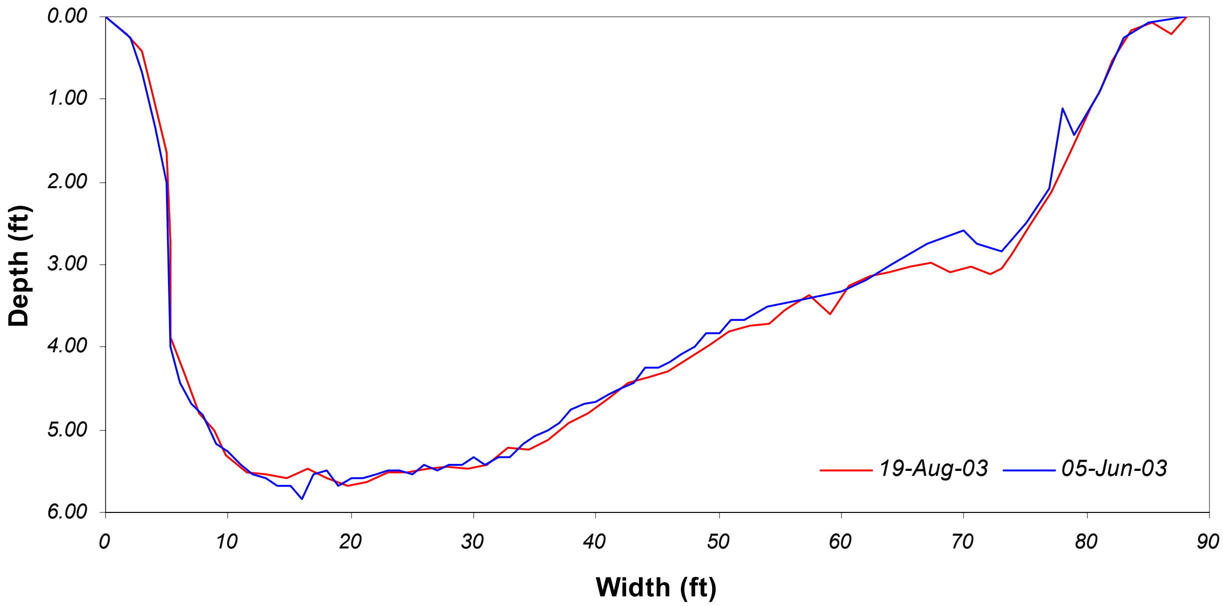


Field Observations

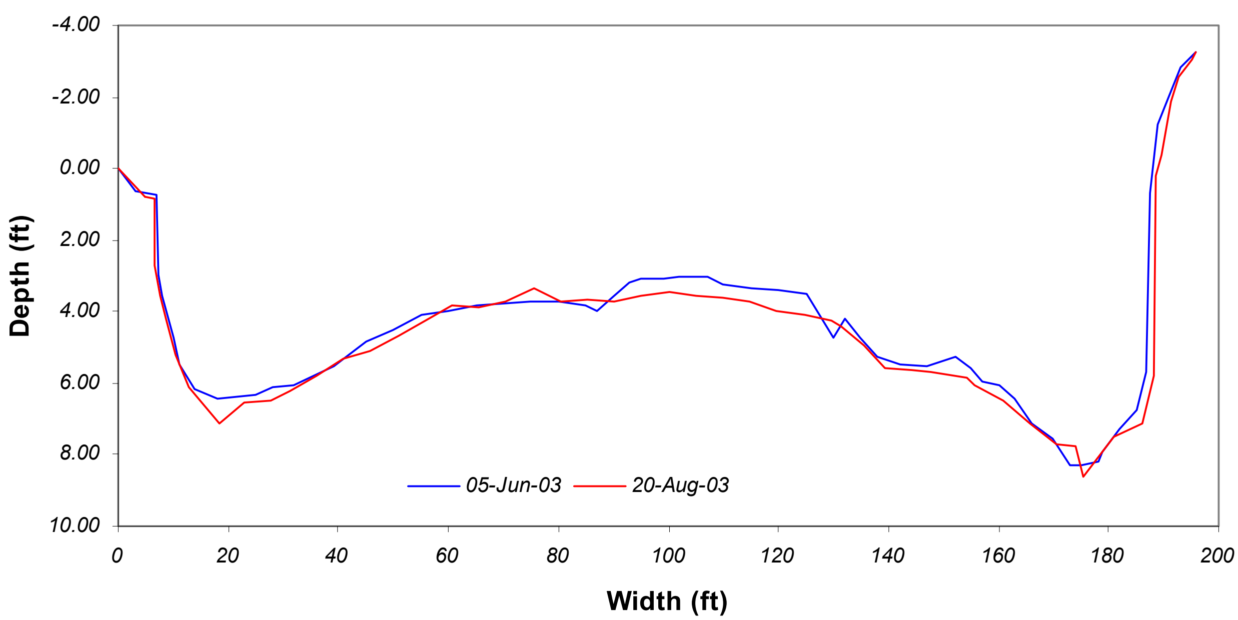
- large point bar deposit along left bank with fresh sand on it
- right bank is vertical and eroded
- confluence on left bank
- several high flow channels also present
- channel substrate is soft and unconsolidated
- left bank majorly undercut
- right bank had a lot of fallen trees and woody debris
- left bank is slumping

APPENDIX C

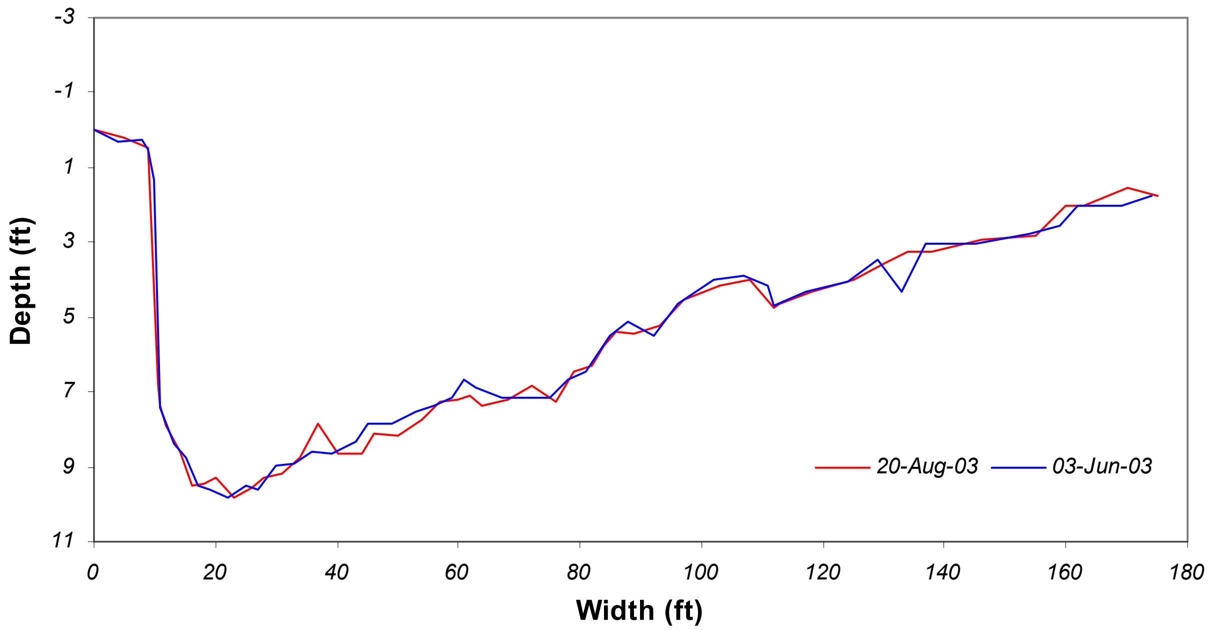
Reach SD-2 - Monitoring Cross-section



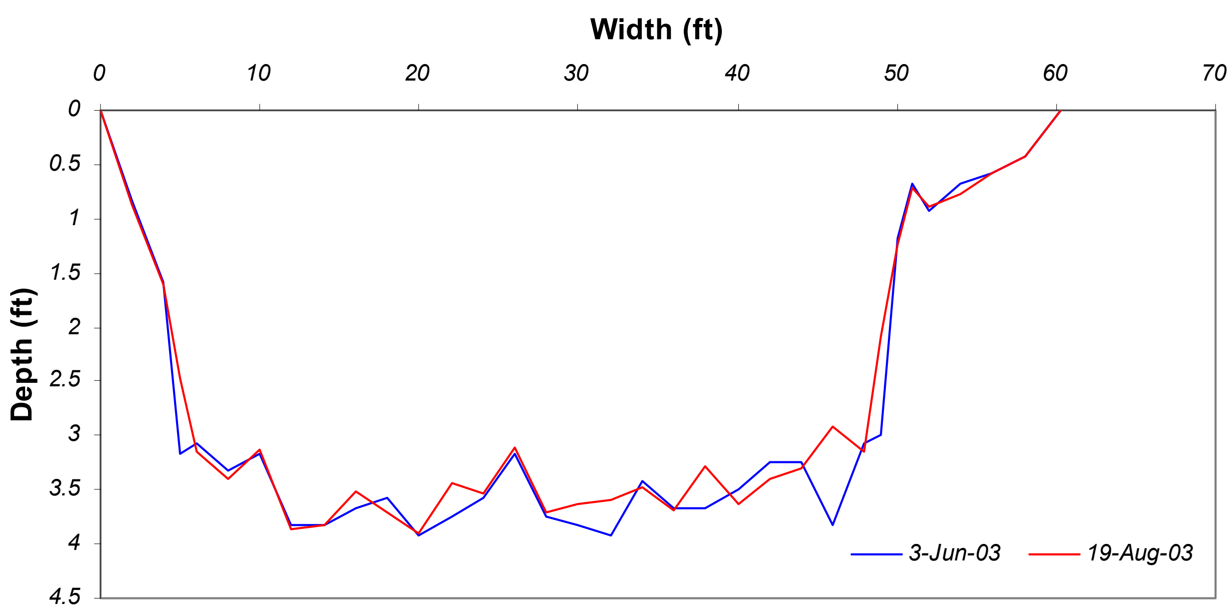
Reach SD-3 Monitoring Cross-section



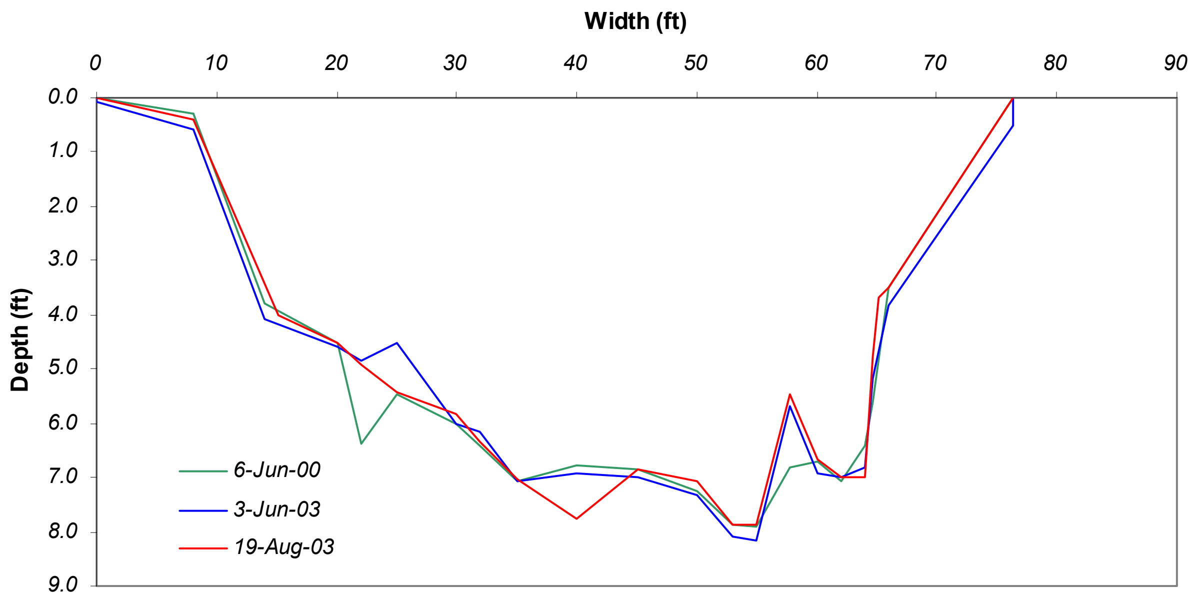
Reach SD-5 - Monitoring Cross Section



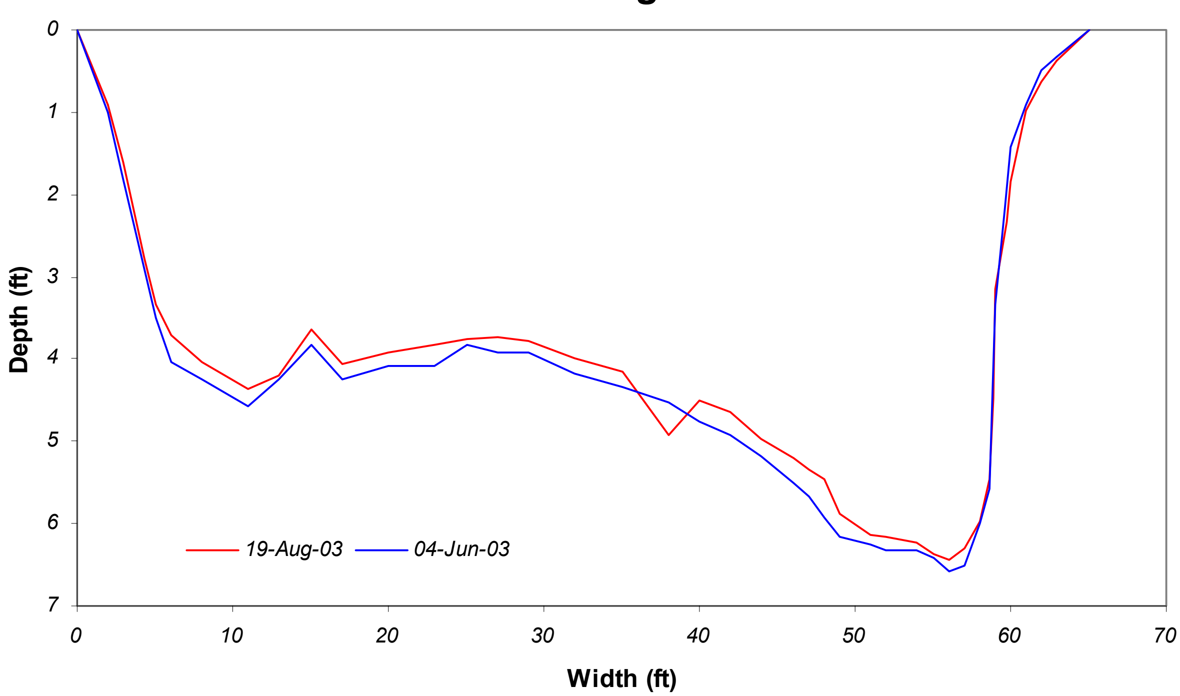
Reach SD-8 - Monitoring Cross-section



Reach SD-10 - Monitoring Cross-section



Reach SD-33 - Monitoring Cross Section



Erosion Pin Monitoring Results for the Sunday River Watershed

Reach Name	EP #	Bank	Location Relative to Cross-Section	June 3-5/03 Exposure (cm)	Aug 19,20/03 Exposure (cm)	Rate of Change (cm/yr)	June 3-5/03 Exposure (In)	Aug 19,20/03 Exposure (In)	Rate of Change (ft/yr)
SD-1	1	Left	- upstream of monitoring x-sec, at end of woody debris	15.9	17.5	-7.7	6.25	6.89	-0.253
	2	Left	- downstream of monitoring x-sec, in front of shaped birch tree	16.5	16.0	2.4	6.50	6.30	0.079
SD-3	1	Right	- 5 to 10 feet downstream of cross section	10.2	10.0	0.8	4.00	3.94	0.025
	2	Left	- at or near the cross section	25.4	64.0	-183.0	10.00	25.20	-6.003
SD-4	1	Left	- furthest ds pin at Herlihy property	15.2	**	**	6.00	**	**
	2	Left	- furthest us pin at Herlihy property	15.2	**	**	6.00	**	**
SD-5	1	Left	- furthest ds pin	14.0	16.5	-12.0	5.50	6.50	-0.395
	2	Left	- centre pin	20.3	21.0	-3.0	8.00	8.25	-0.099
	3	Left	- furthest us (bottom) pin	20.3	20.3	0.0	8.00	8.00	0.000
	4	Left	- furthest us (top) pin	15.2	11.4	18.1	6.00	4.50	0.593
SD-8	1	Left	- at monitoring cross section	11.5	**	**	4.50	**	**
	2	Right	- at monitoring cross section	16.5	**	**	6.50	**	**
SD-10	1	Left	- 300 feet upstream of monitoring cross section	15.2	18.0	-13.1	6.00	7.09	-0.429
	2	Right		14.0	14.0	-0.1	5.50	5.51	-0.005
SD-21	1	Left	- 15 ft upstream of the monitoring cross-section	18.0	**	**	6.00	**	**
	2	Right	- right bank at monitoring cross-section	18.0	**	**	6.00	**	**
SD-33	1	Right	~15m upstream of Monitoring cross-section	15.2	16.5	-6.0	6.00	6.50	-0.198
	2	Right	- at cross-section	15.2	11.8	16.5	6.00	4.63	0.541

** = No results available
1 - loss of bank material
1 - gain of bank material

Averages

	(cm/yr)	(ft/yr)
Overall	*-15.6*	*-0.512*
Overall - without SD-3 EP #2:	*-0.4*	*-0.013*
Sites demonstrating gains of bank material:	9.4	0.309
Sites demonstrating losses of bank material:	-28.1	-0.923
Sites demonstrating losses of bank material - without SD-3 EP #2:	-6.0	-0.197

Appendix D

Figure 5.1

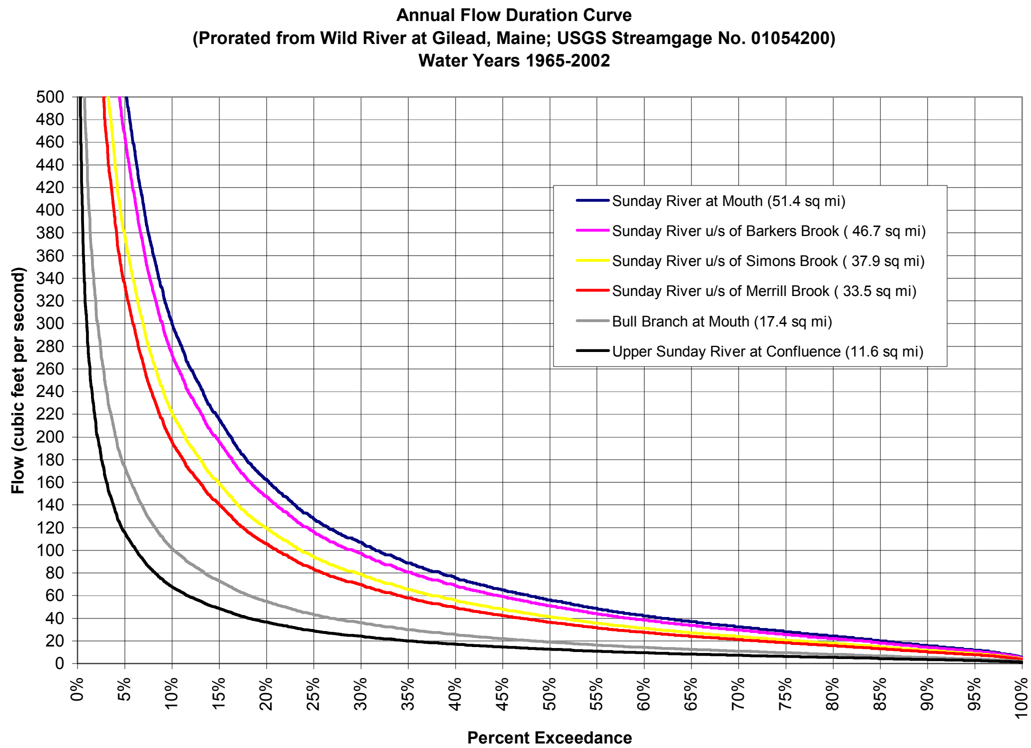


Figure 5.2

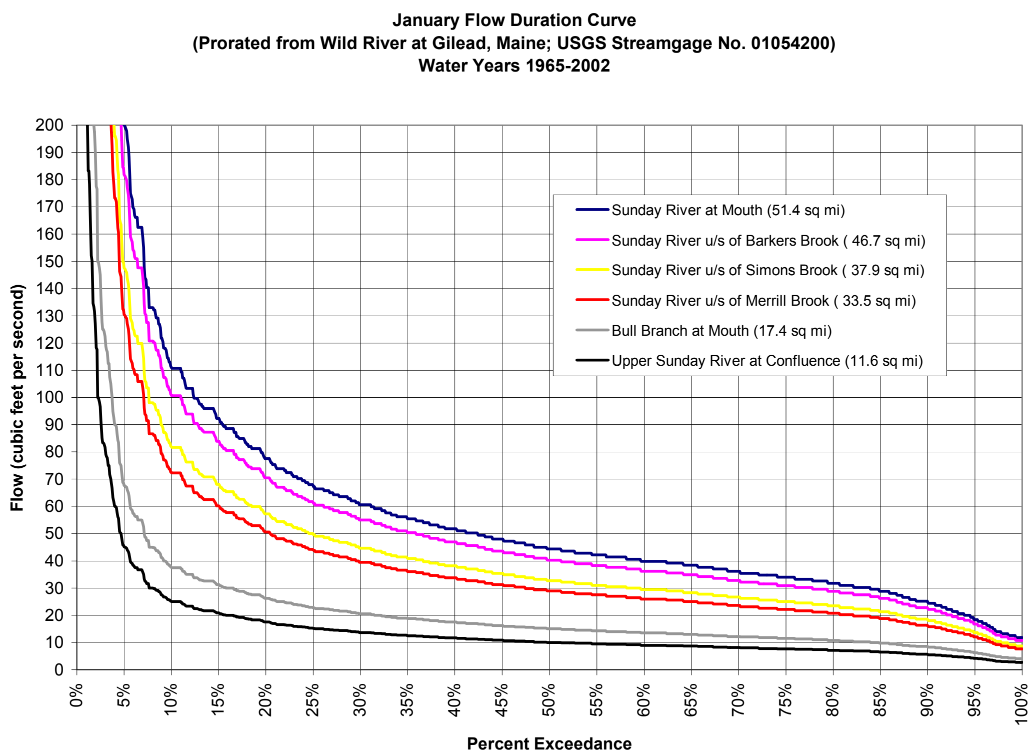


Figure 5.3

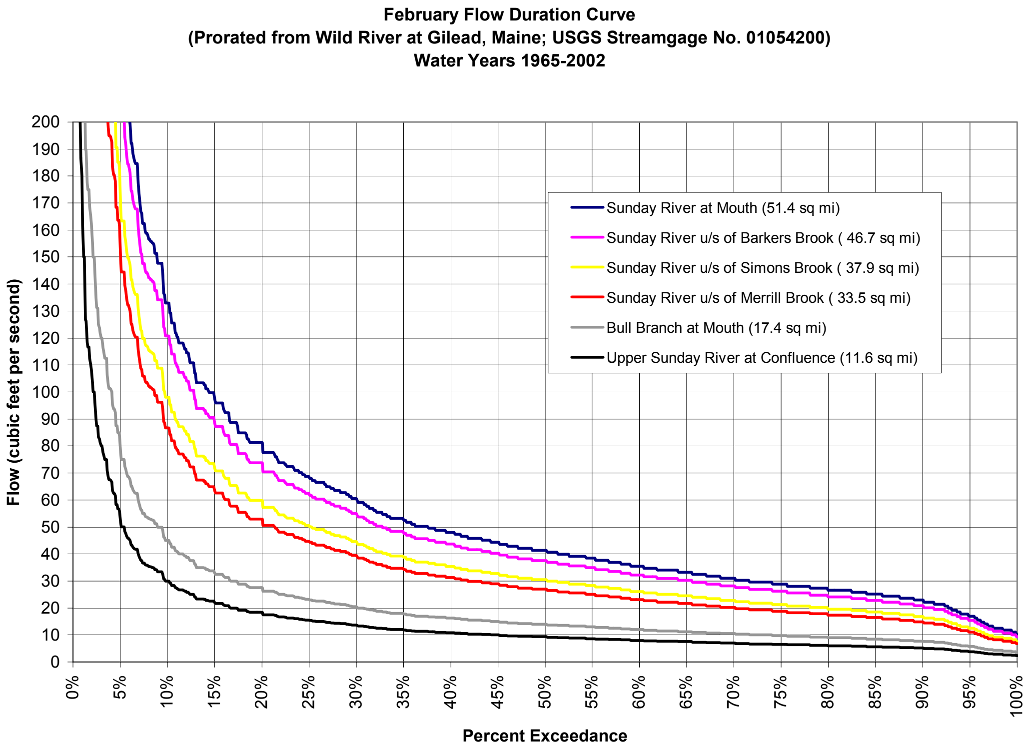


Figure 5.4

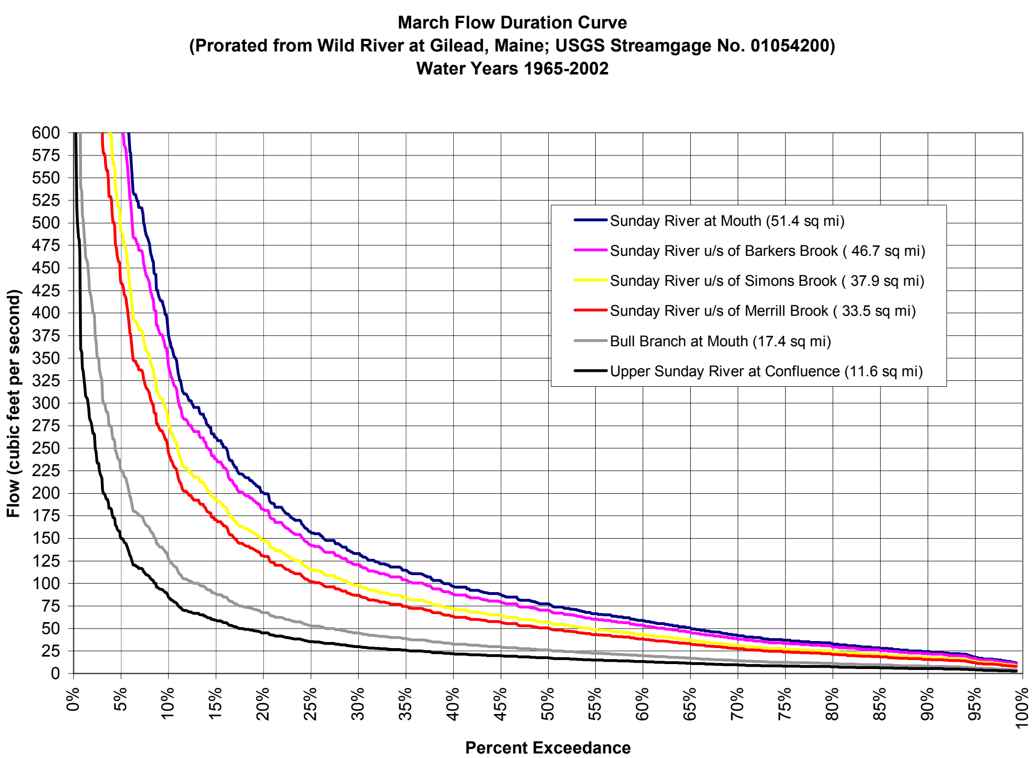


Figure 5.5

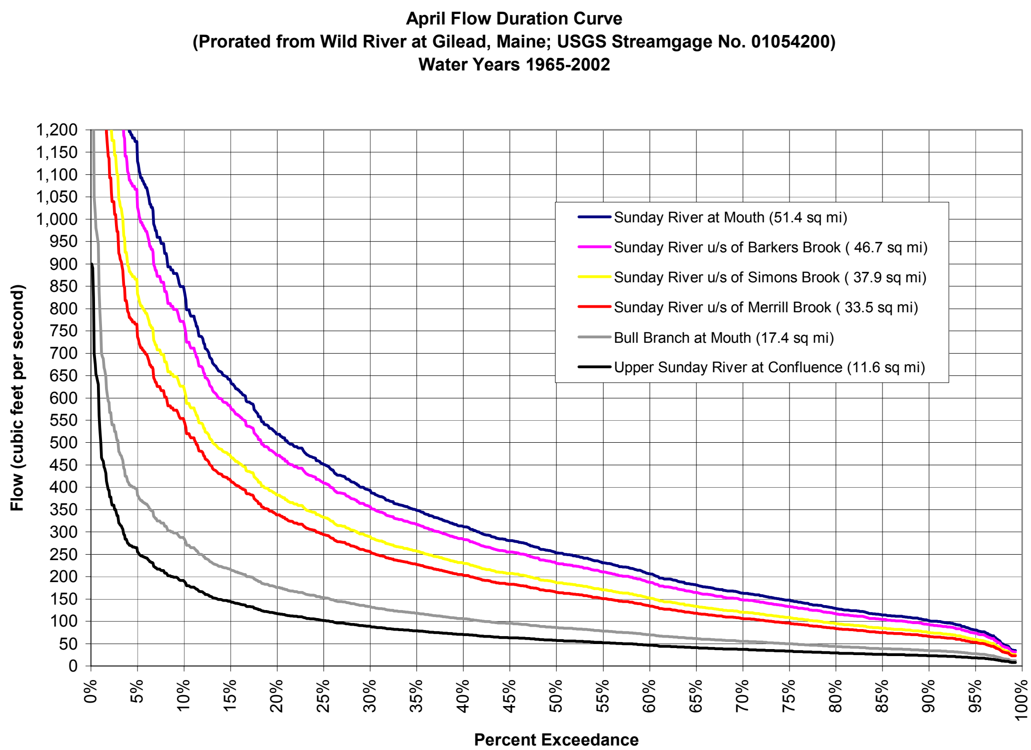


Figure 5.6

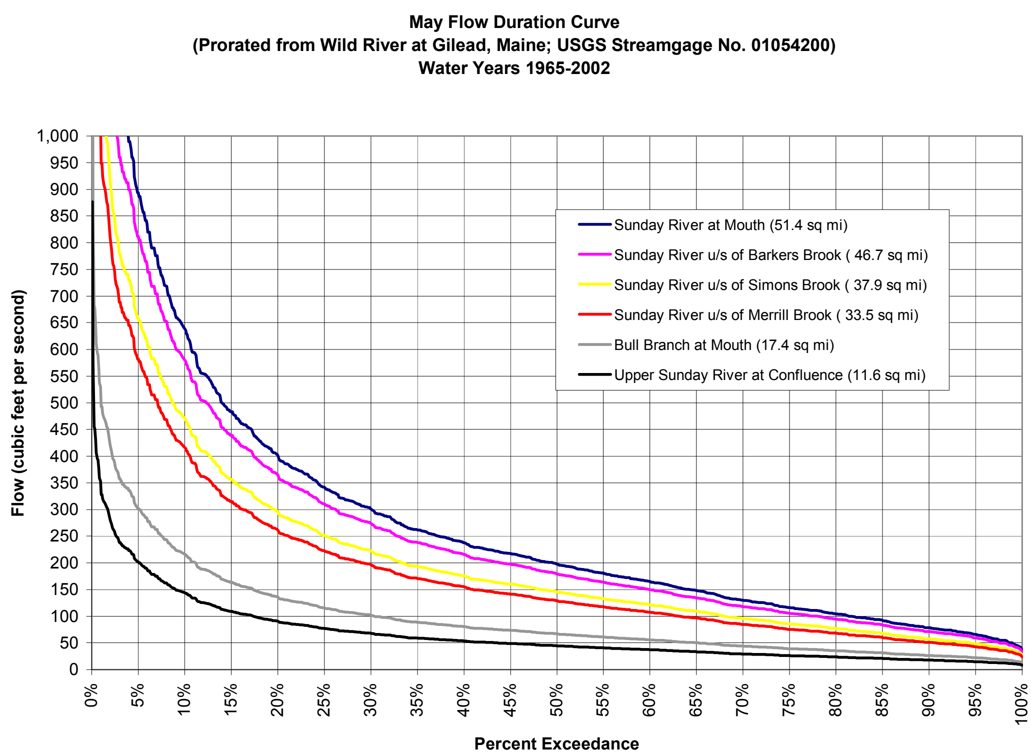


Figure 5.7

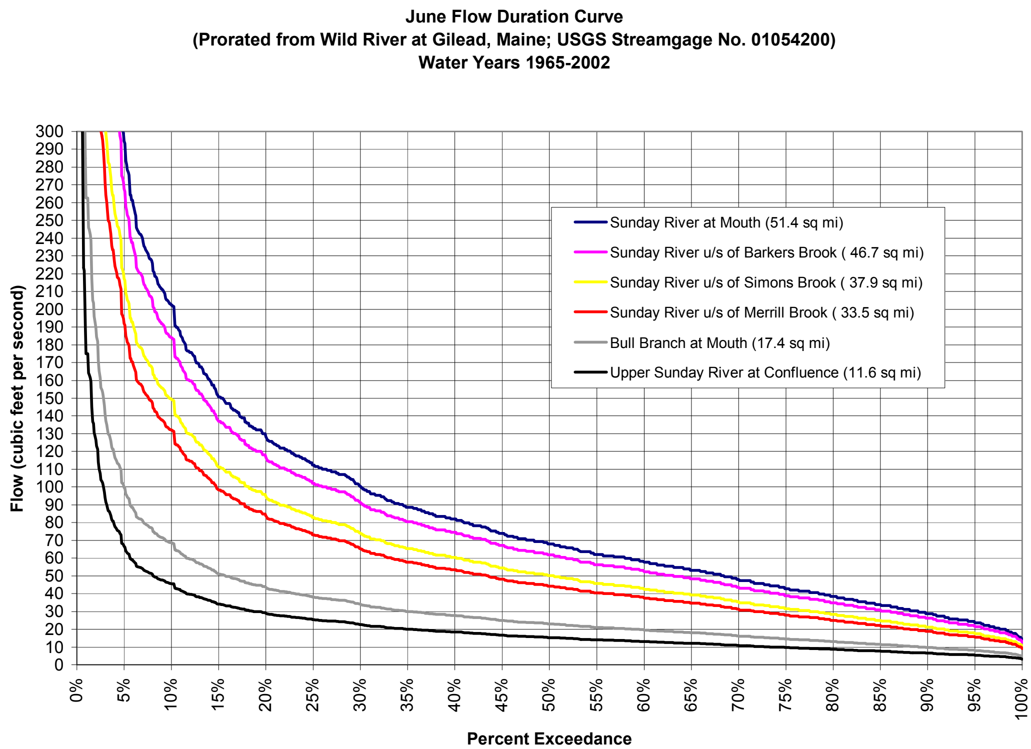


Figure 5.8

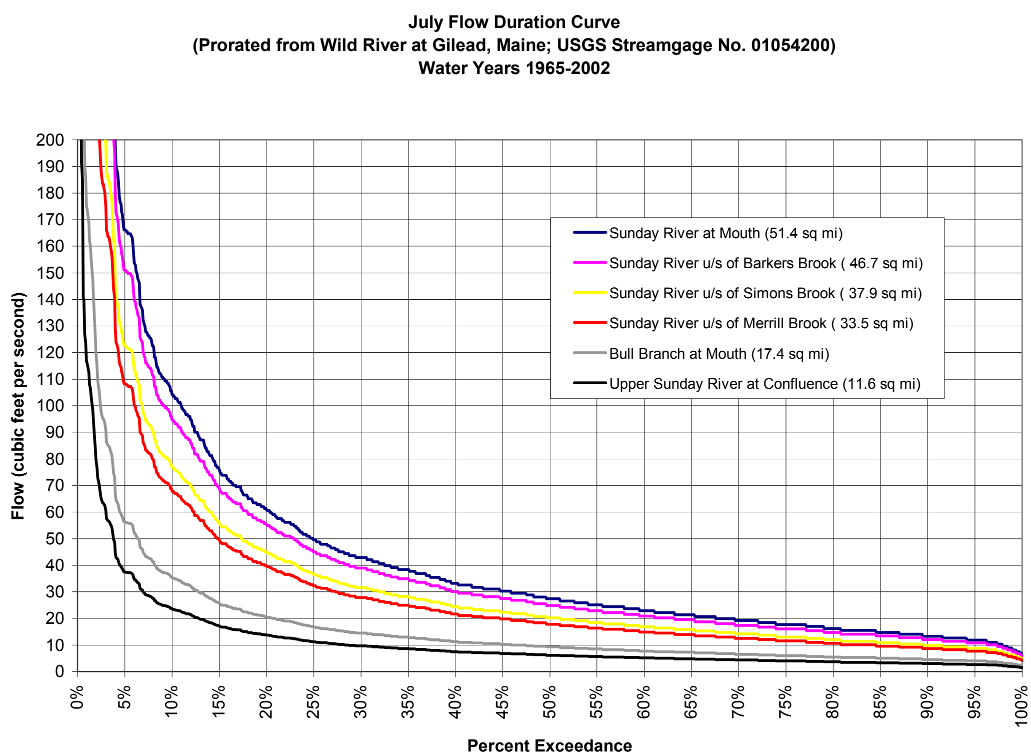


Figure 5.9

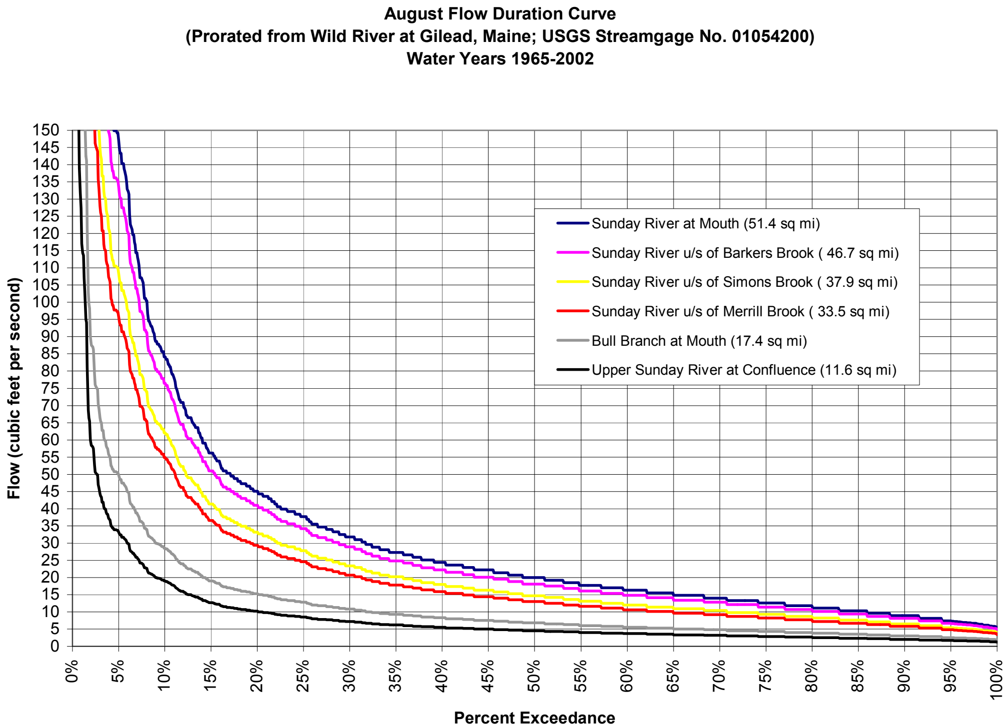


Figure 5.10

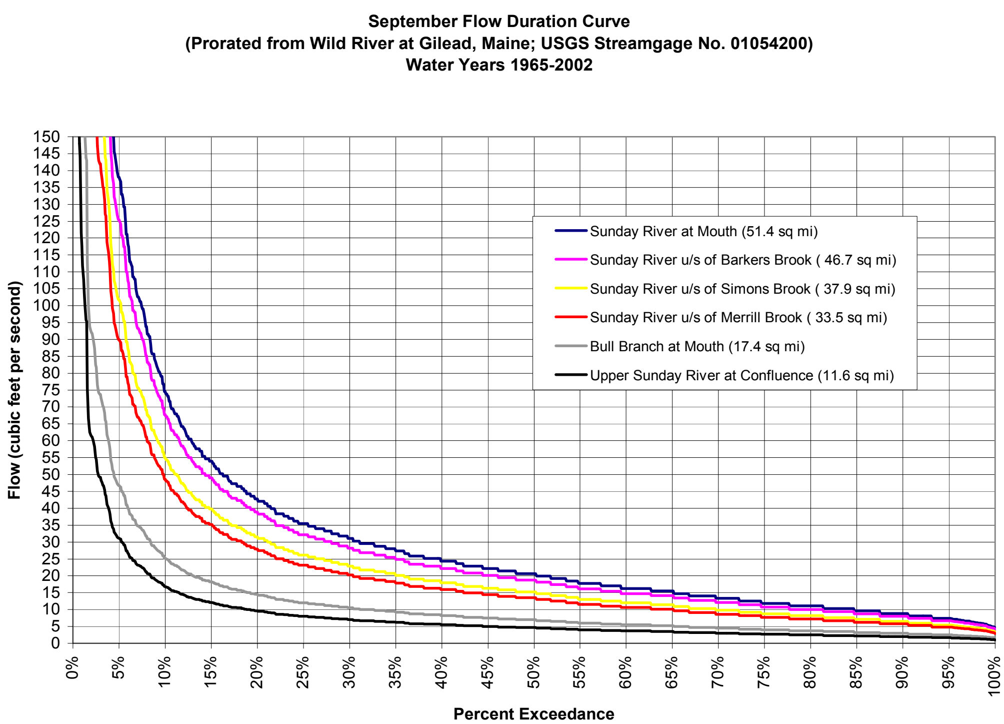


Figure 5.11

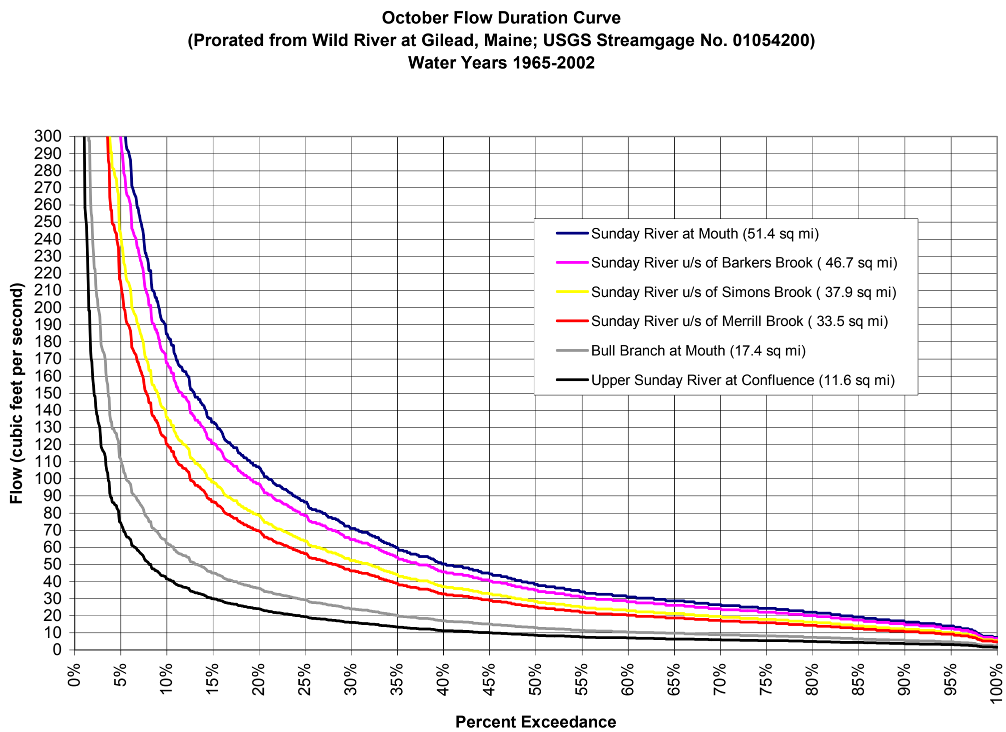


Figure 5.12

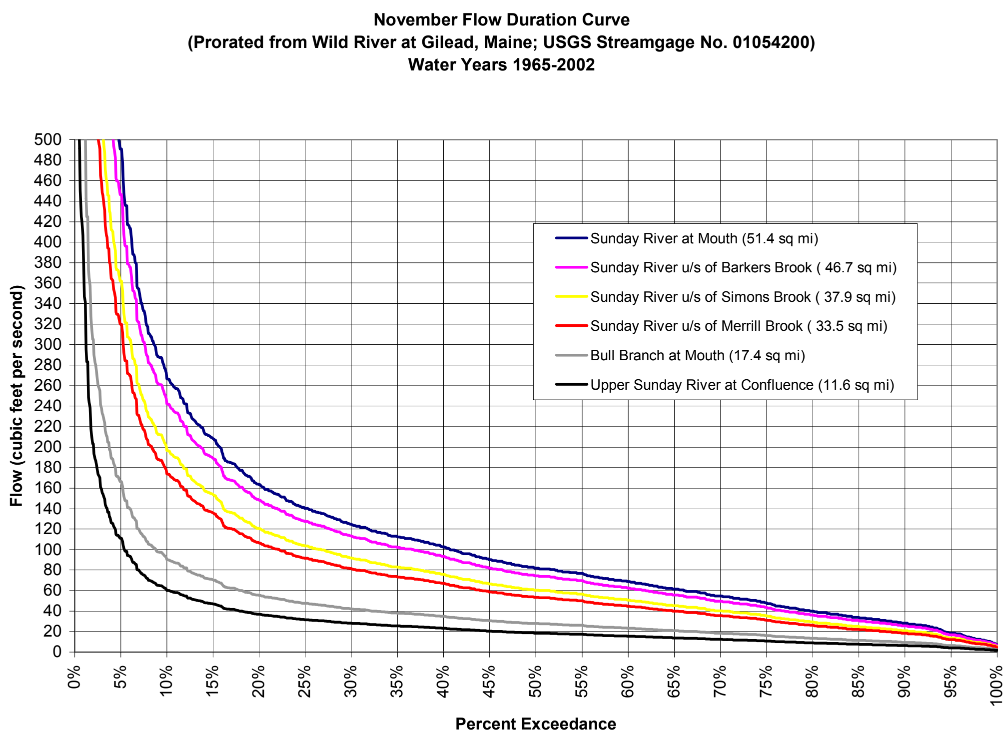


Figure 5.13

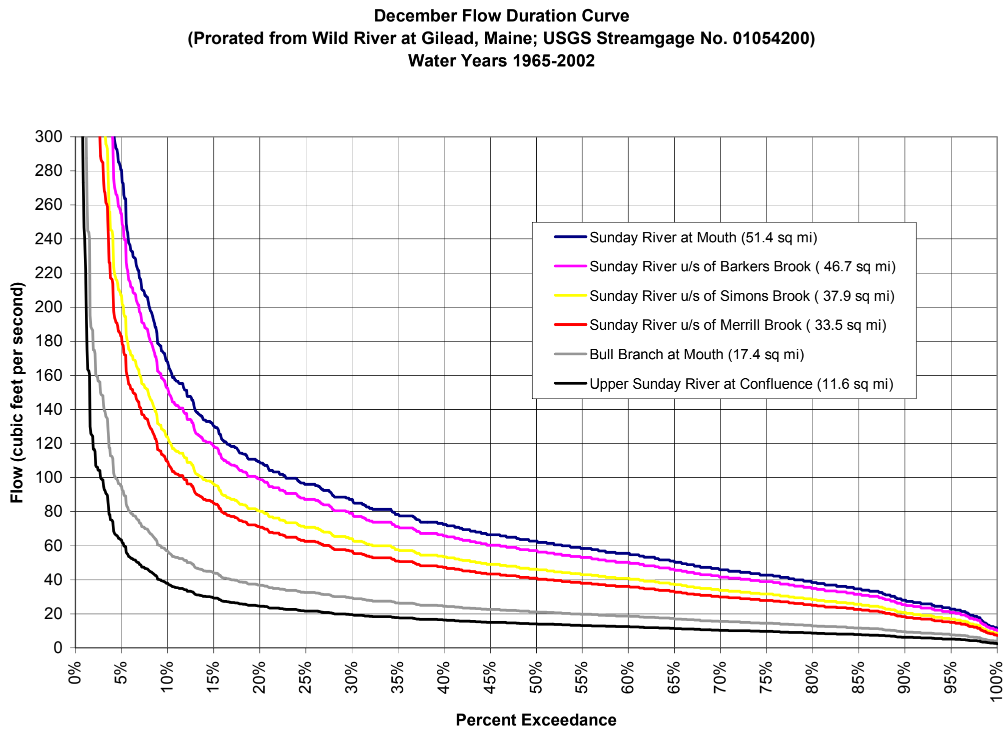


Figure 5.14

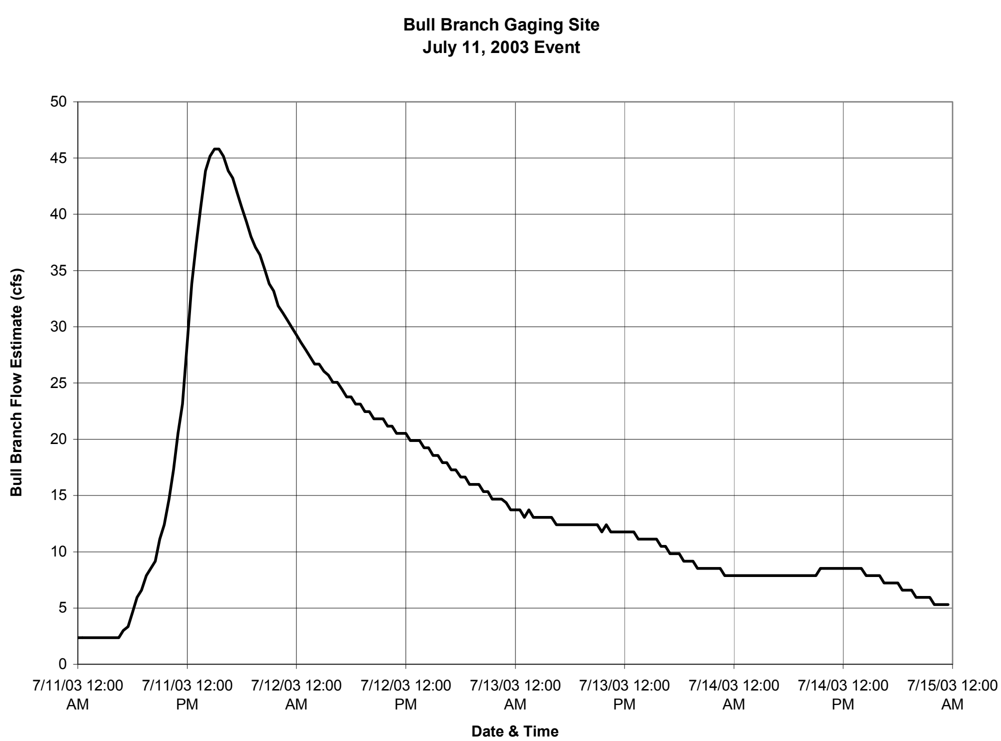


Figure 5.15

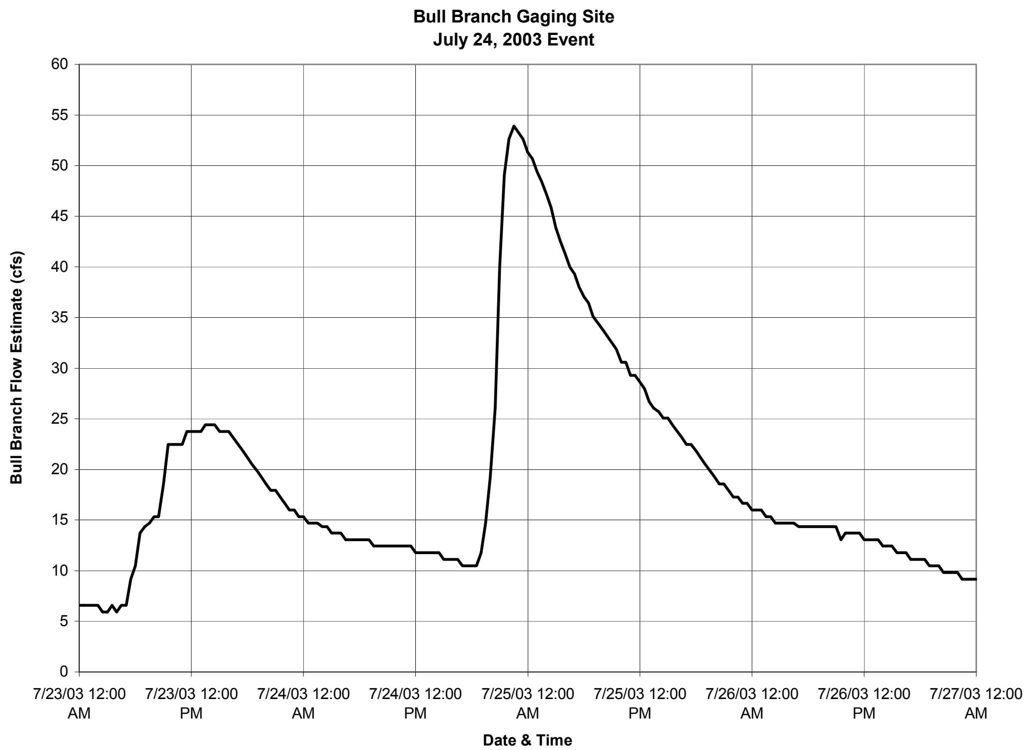


Figure 5.16

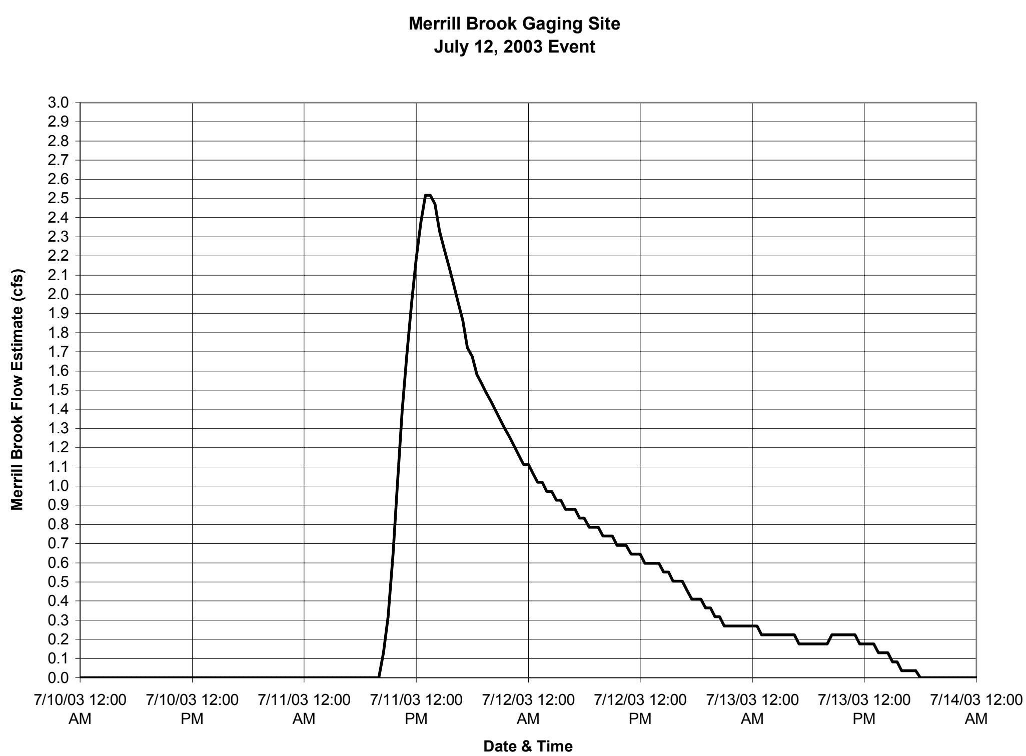


Figure 5.17

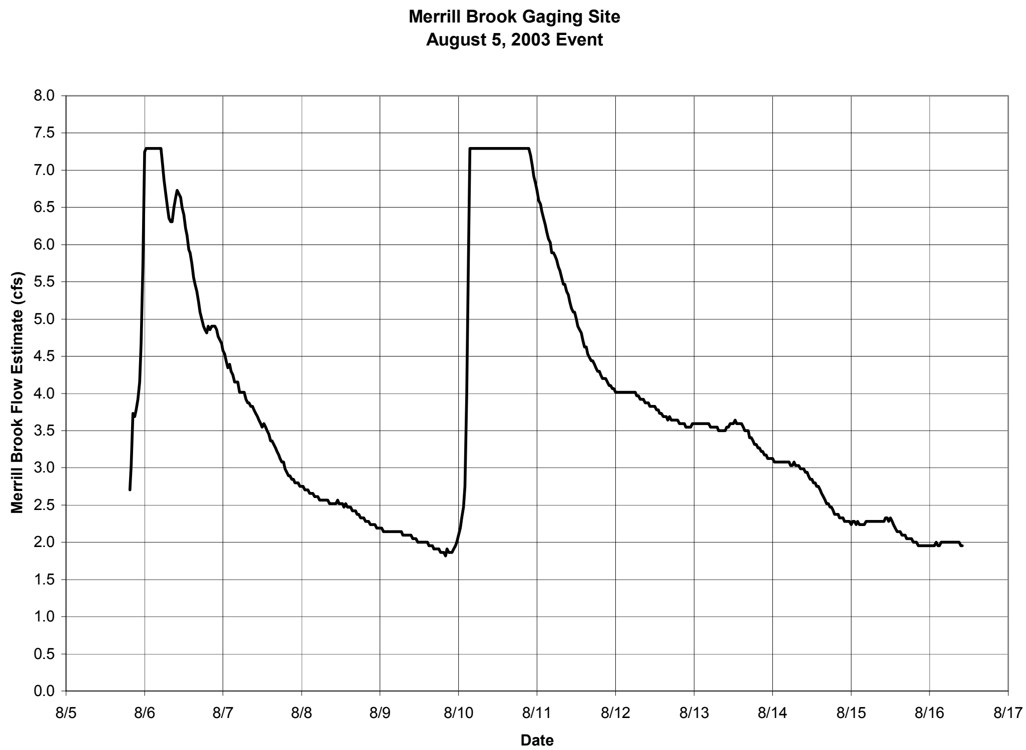


Figure 5.18

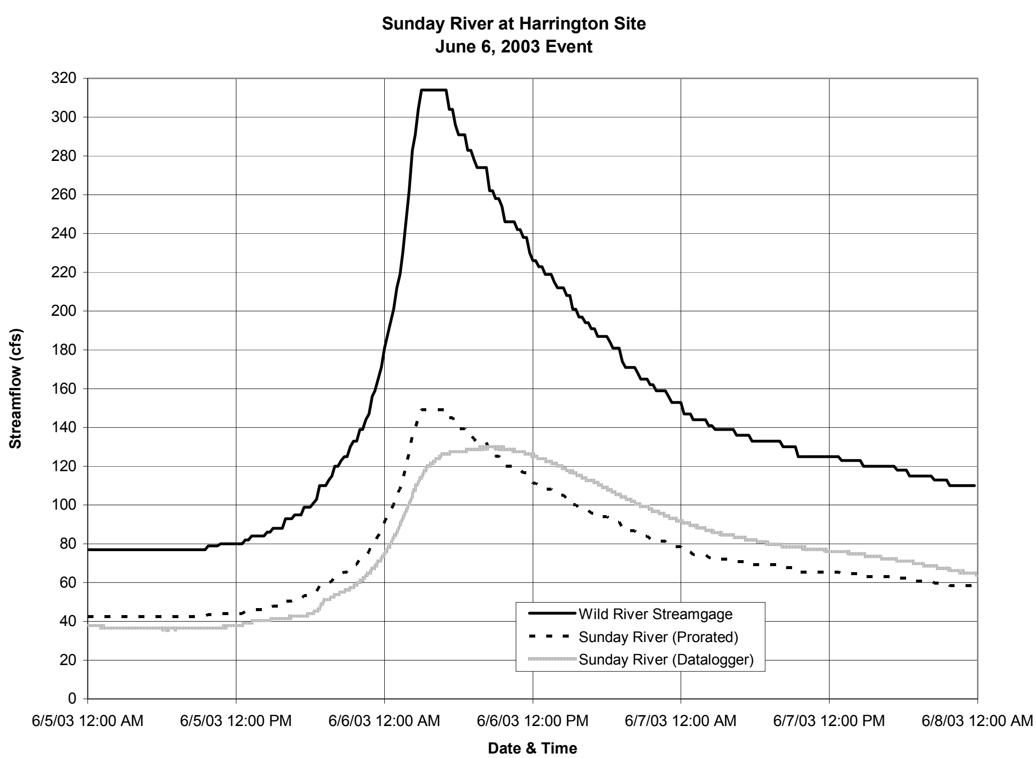


Figure 5.19

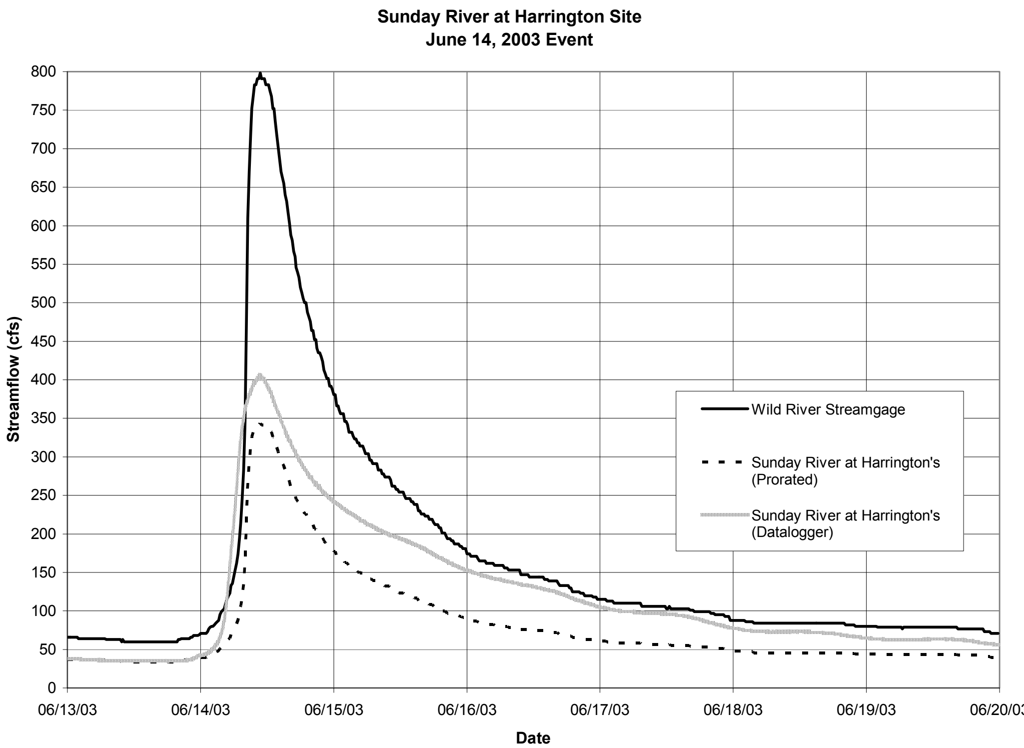


Figure 5.20

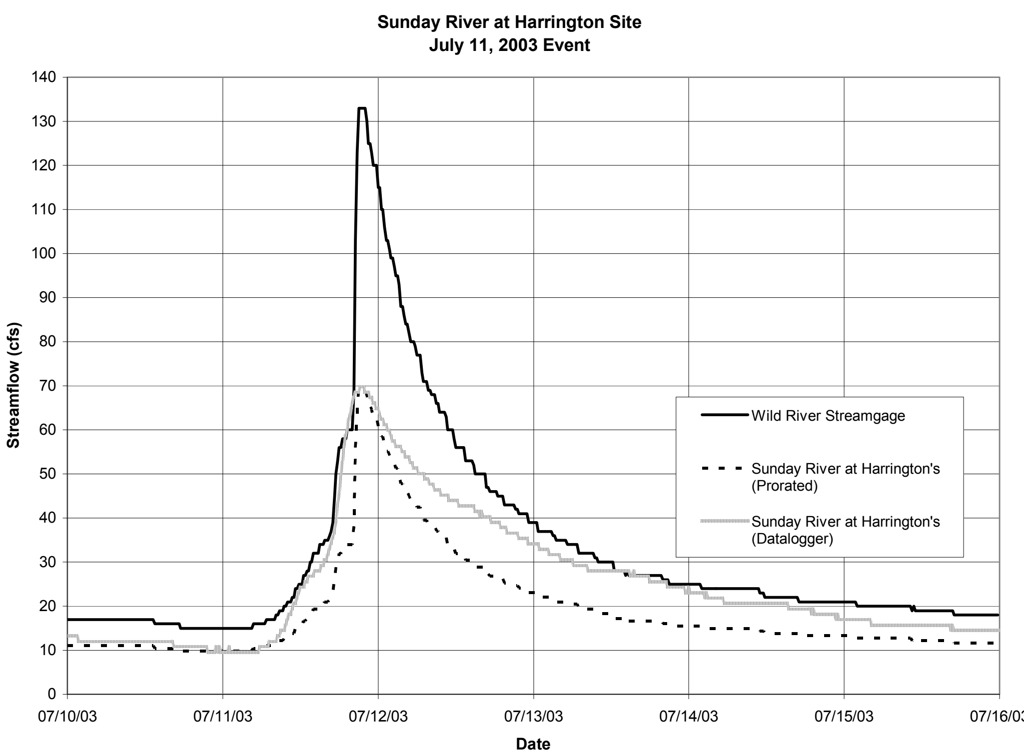


Figure 5.21

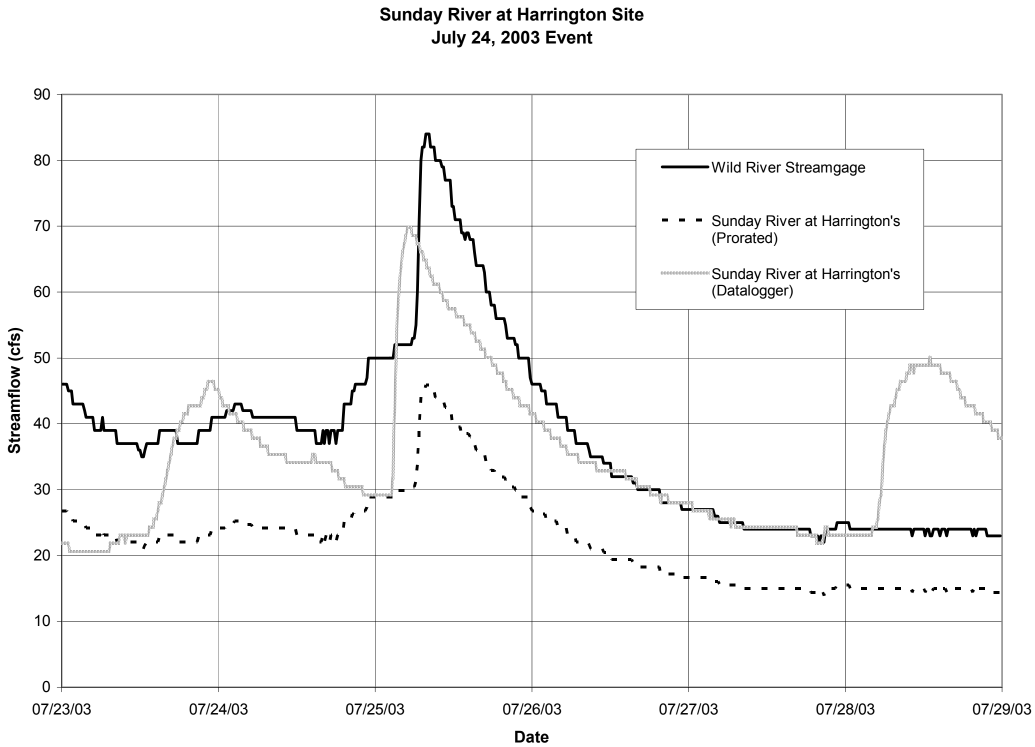


Figure 5.22

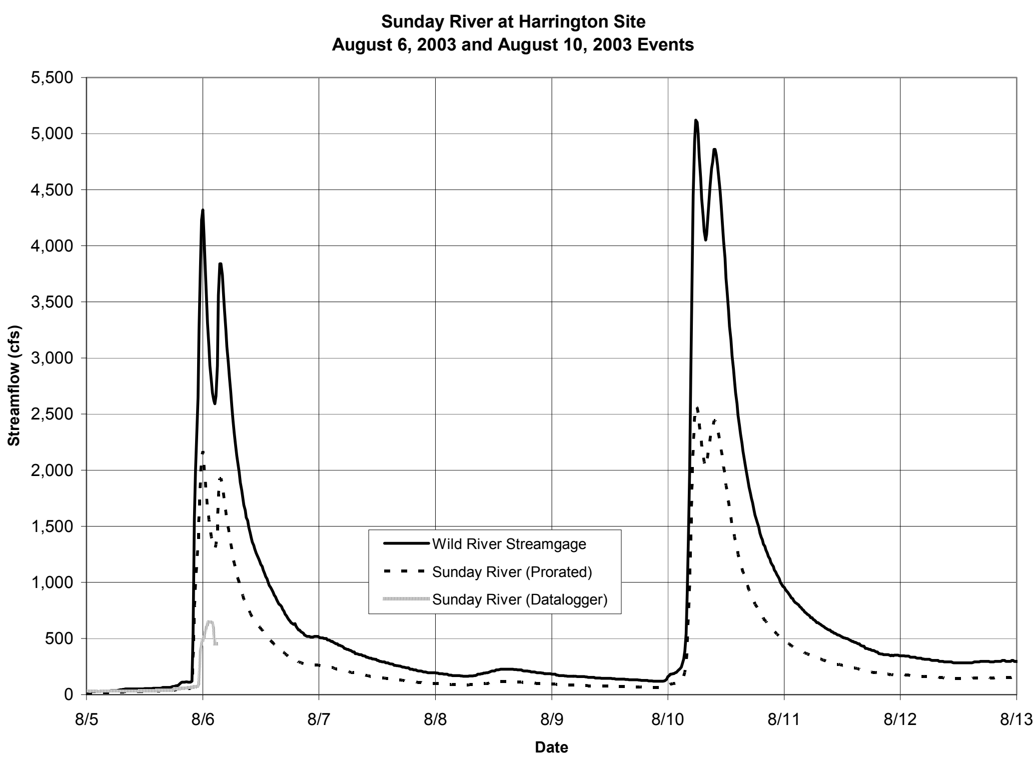


Table 5.1

USGS 01054200 Wild River at Gilead, Maine

Date	Peak Q (cfs)	
October 24, 1959	28,300	(Surveyed from flood marks.)
November 26, 1964	1,500	
April 22, 1966	1,680	
November 3, 1966	16,800	
April 25, 1968	14,400	
July 30, 1969	5,930	
December 27, 1969	11,200	
May 4, 1971	4,110	
May 7, 1972	2,780	
June 30, 1973	7,940	
December 21, 1973	7,990	
December 9, 1974	5,300	
April 1, 1976	8,390	
October 21, 1976	13,000	
January 9, 1978	8,000	
April 27, 1979	10,600	
April 10, 1980	6,560	
February 21, 1981	8,760	
April 27, 1982	4,090	
January 11, 1983	6,410	
April 5, 1984	16,700	
September 27, 1985	7,800	
January 27, 1986	14,600	
March 31, 1987	17,000	
April 29, 1988	8,000	
May 12, 1989	9,000	
August 11, 1990	7,830	
August 19, 1991	13,300	
October 6, 1991	8,430	
April 17, 1993	9,040	
November 28, 1993	7,380	
January 21, 1995	1,970	
October 22, 1995	24,500	
October 21, 1996	8,750	
June 14, 1998	19,200	
September 17, 1999	18,100	
April 9, 2000	11,200	
December 17, 2000	8,060	
April 14, 2002	9,250	

Figure 5.2

Drainage Area (km^2)	Drainage Area (mi^2)	Percent Wetlands		2-year	5-year	10-year	25-year	50-year	100-year	500-year
180	69.6	0.7%	m^3/sec	242	374	464	589	685	782	1,030
			ft^3/sec	8,546	13,208	16,386	20,800	24,190	27,616	36,374
			ft^3/sec/mi^2	123	190	235	299	348	397	523

Prorated from Wild River Streamgage

				2-year	5-year	10-year	25-year	50-year	100-year	500-year
45	17.4	0.2%	ft^3/sec	2,137	3,302	4,096	5,200	6,048	6,904	9,093
30	11.6	0.3%	ft^3/sec	1,424	2,201	2,731	3,467	4,032	4,603	6,062
87	33.5	0.2%	ft^3/sec	4,113	6,357	7,887	10,012	11,643	13,292	17,508
98	37.9	0.2%	ft^3/sec	4,654	7,192	8,923	11,327	13,173	15,038	19,807
121	46.7	0.9%	ft^3/sec	5,734	8,862	10,995	13,956	16,231	18,530	24,406
133	51.4	0.9%	ft^3/sec	6,311	9,754	12,101	15,361	17,865	20,395	26,862

USGS Regression Equations

				2-year	5-year	10-year	25-year	50-year	100-year	500-year
45	17.4	0.2%	ft^3/sec	939	1,530	1,986	2,612	3,116	3,654	5,037
30	11.6	0.3%	ft^3/sec	663	1,093	1,426	1,887	2,260	2,660	3,691
87	33.5	0.2%	ft^3/sec	1,638	2,623	3,374	4,391	5,205	6,068	8,271
98	37.9	0.2%	ft^3/sec	1,819	2,902	3,727	4,841	5,730	6,673	9,077
121	46.7	0.9%	ft^3/sec	2,074	3,277	4,187	5,410	6,382	7,410	10,020
133	51.4	0.9%	ft^3/sec	2,255	3,554	4,534	5,850	6,895	7,999	10,800

Town of Newry, Maine Flood Insurance Study

				2-year	5-year	10-year	25-year	50-year	100-year	500-year
	33.5		ft^3/sec						5,280	
	37.9		ft^3/sec						5,820	
	46.7		ft^3/sec						6,880	
	50.0		ft^3/sec						7,270	

APPENDIX E

Existing Conditions
- Very high rates of channel migration and adjustment.
- Bank erosion prevalent, some large depositional features.
- Channel slightly entrenched with highly variable widths.
- Possible historic loss of floodplain wetlands due to farming etc..

Summary of Analysis
- Representative detailed data collection.
- RGA (0.59) indicates the channel is *In Adjustment.*
- RSAT (21) indicates that the channel has *Moderate Stability.*

Potential Restoration
- Re-grade and stabilize banks to control channel migration.
- Widen and re-align sections of channel to reduce erosion rates.

Functions Enhanced
- Flood storage.
- Control sediment supply / transport.
- Wildlife habitat.
- Reduce risk to property and infrastructure.

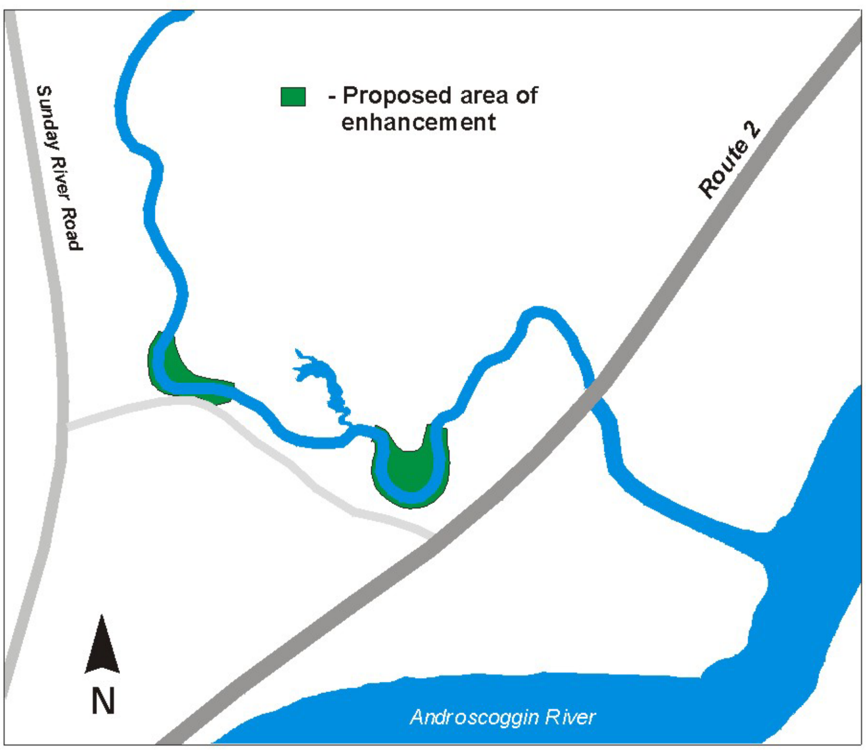


Figure 1. Location of proposed channel enhancements in Reach SD-1.

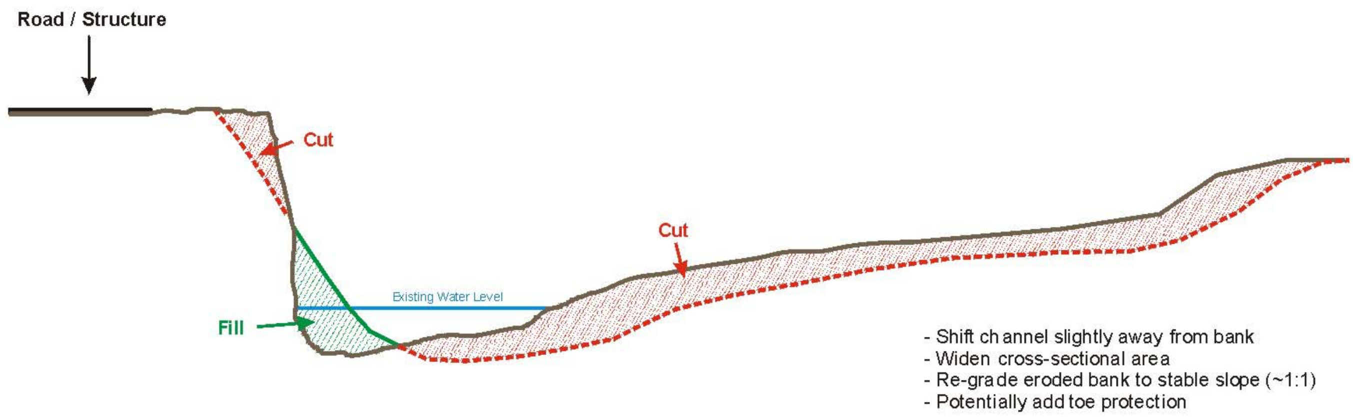


Figure 2. Proposed cross-sectional improvements to reduce local erosion issues.

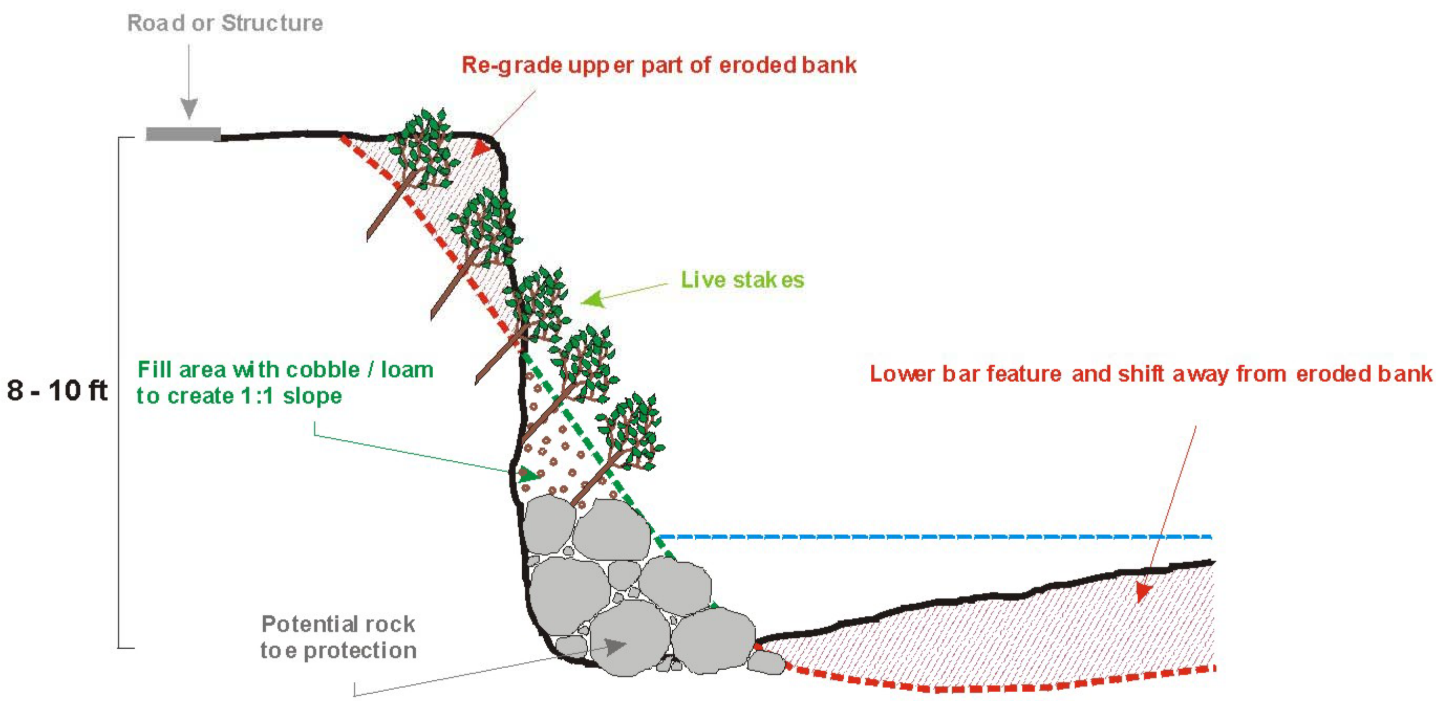


Figure 3. Proposed bank stabilization techniques for localized areas of Reach SD-1.

Existing Conditions

- Very high rates of channel migration.
- Some areas of high channel erosion, other areas have high rates of deposition.
- Channel slightly entrenched.
- Possible historic loss of floodplain wetlands.

Summary of Analysis

- Monitoring site.
- Hydrological monitoring.
- Representative detailed data collection.
- RGA (0.52) indicates the channel is *In Adjustment.*
- RSAT (24) indicates that the channel has *Moderate Stability.*

Potential Restoration

- Re-grade and stabilize banks to control channel migration.
- Creation of floodplain wetlands.

Functions Enhanced

- Flood storage.
- Control sediment supply / transport.
- Wildlife habitat.

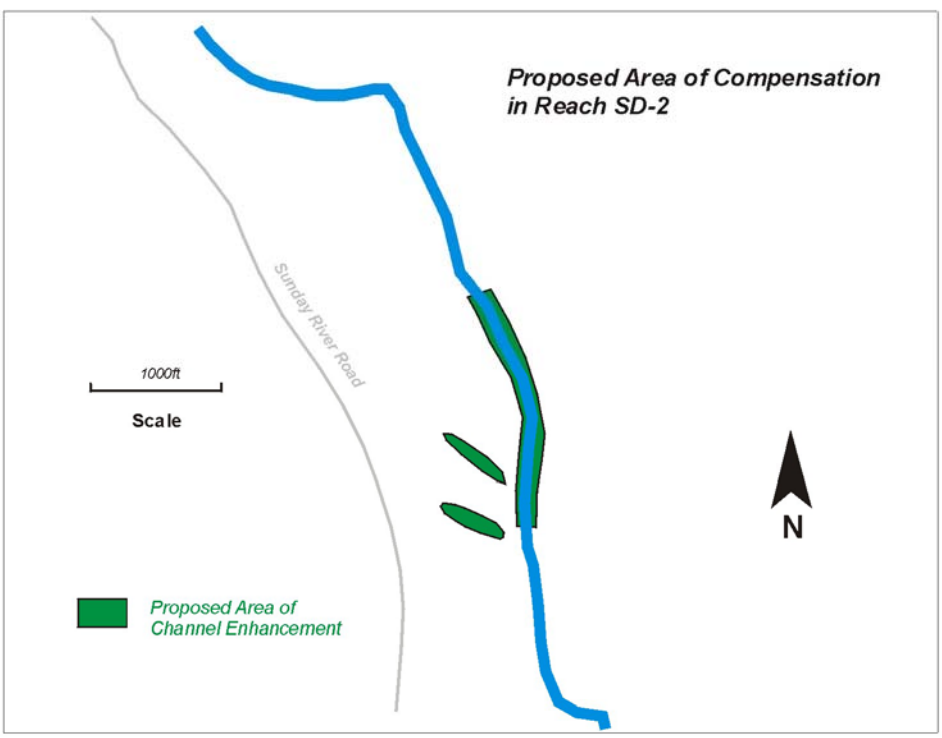


Figure 1. Location of proposed channel enhancements in Reach SD-2.

Photo 1. Area of bank erosion in Reach SD-2.

Photo 2. Area of deposition in Reach SD-2.

Existing Conditions

- High rates of channel migration with corresponding extensive bank erosion.
- Very large bar deposit.
- Channel is entrenched and is functionally removed from its floodplain.

Summary of Analysis

- Historic monitoring site (MIF&W).
- Hydrological monitoring site.
- Detail field data collection.
- RGA (0.72) indicates the channel is *In Adjustment.*
- RSAT (30) indicates that the channel has *Moderate Stability.*

Potential Restoration

- Re-grade banks.
- Narrow channel cross-section.
- Remove portion of existing bar deposit.

Functions Enhanced

- Sediment supply reduced (bank erosion).
- Sediment transport improved.
- Aquatic habitat.

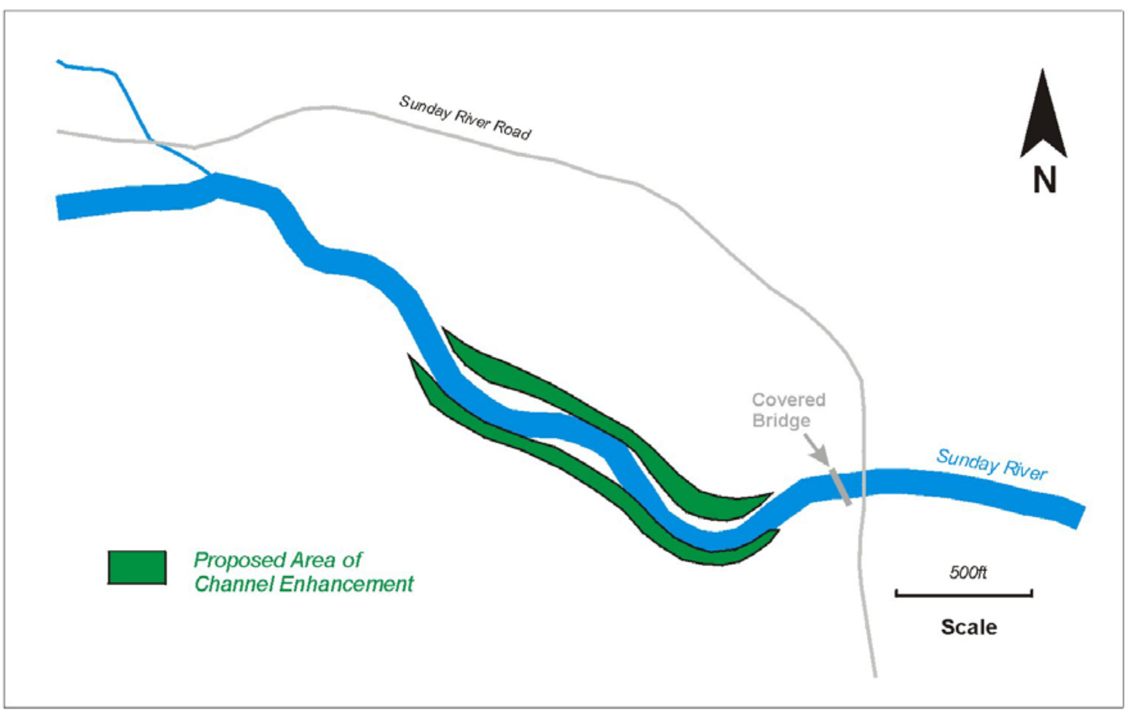


Figure 1. Location of proposed channel enhancements above covered bridge (SD-3).

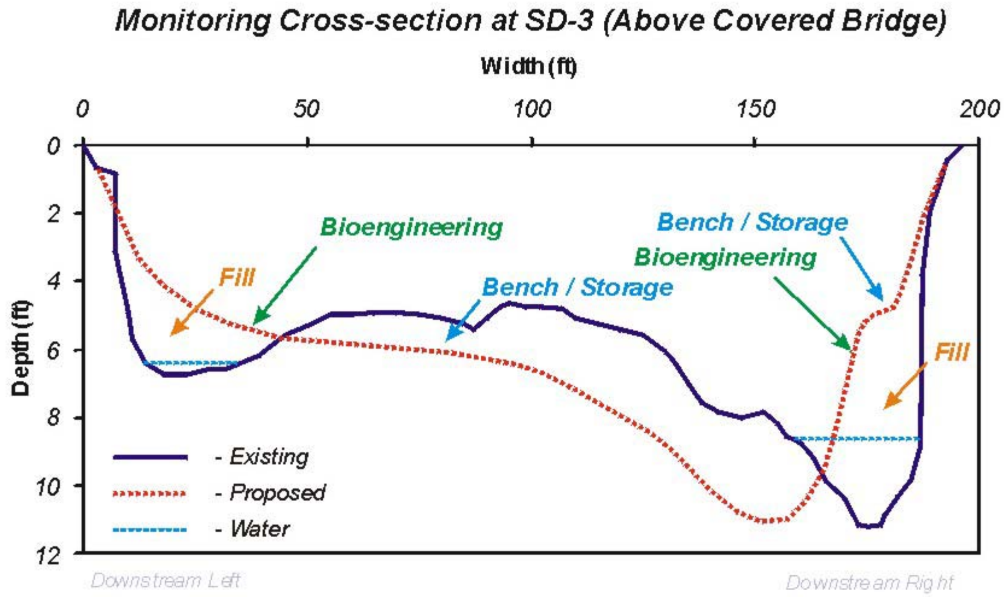


Figure 2. Proposed cross-section at location of existing Monitoring Site for SD-3.

Photo 1. Right side of channel at monitoring site SD-3 (see Figure 2).

Existing Conditions
- High rates of bank erosion, associated with channel adjustments.
- Channel erosion is threatening road.
- High width to depth ratio.

Summary of Analysis
- Channel monitoring including erosion pins.
- Detailed data collection.
- RGA (0.37) indicates the channel is *Transitional or Stressed.*
- RSAT (27) indicates that the channel has *Moderate Stability*.

Potential Restoration
- Bank stabilization, including bioengineering techniques.
- Narrow the channel to enhance sediment transport.
- Additional plantings in riparian zone.

Functions Enhanced
- Sediment supply and transport.
- Aquatic and wildlife habitat.

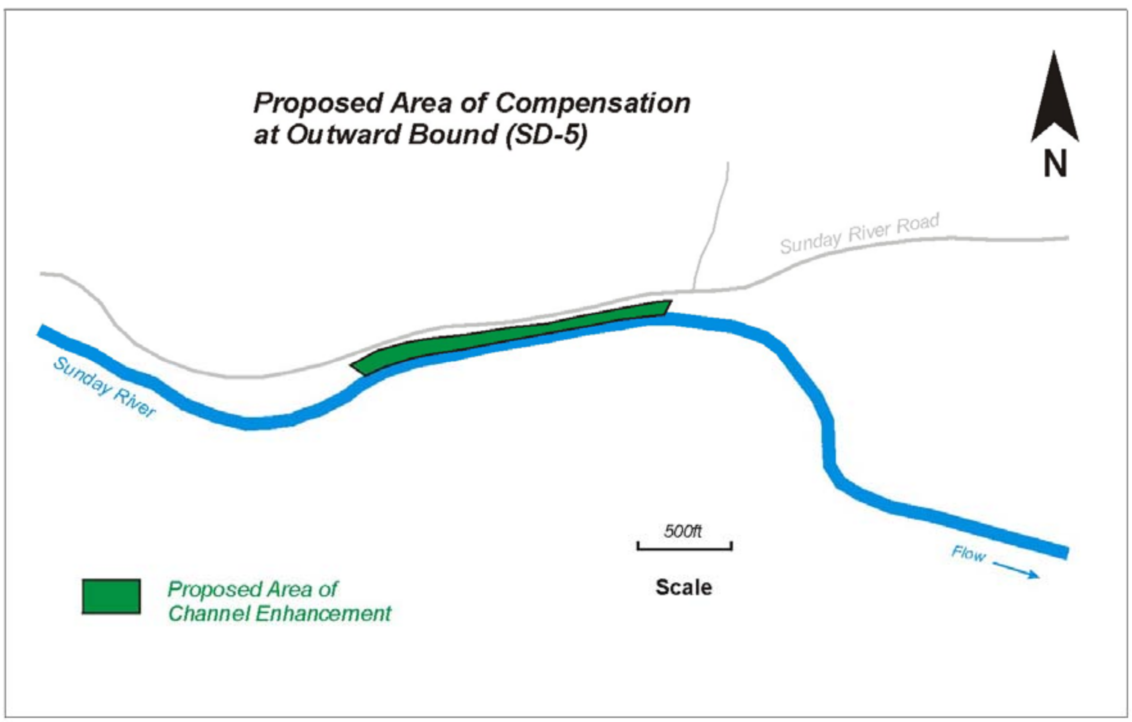


Figure 1. Location of proposed channel enhancements adjacent to the Outward Bound Site (SD-5).

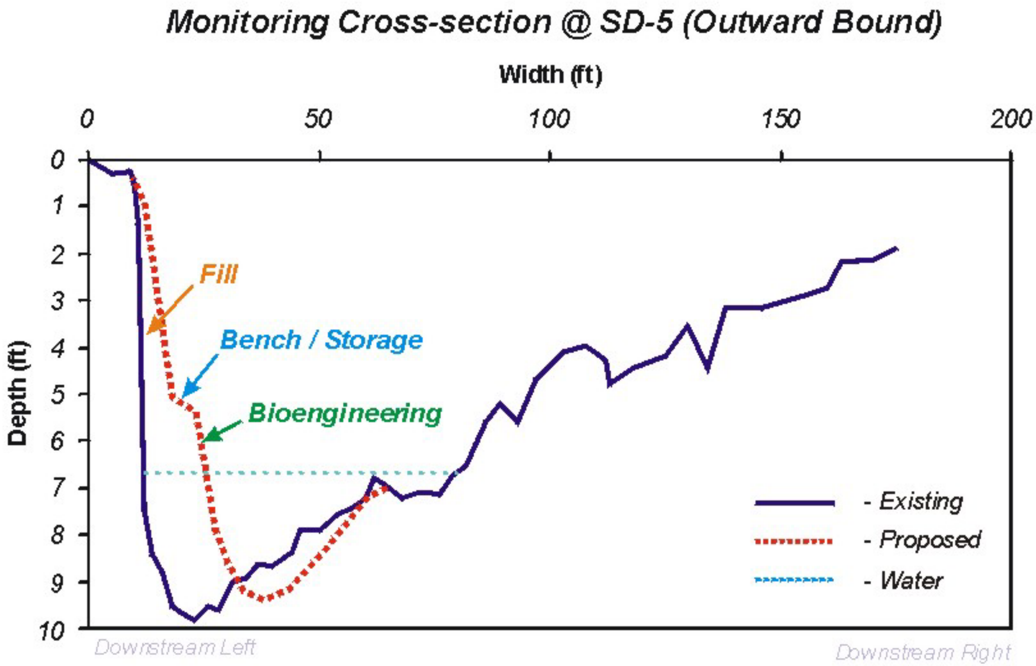


Figure 2. Proposed cross-section at location of existing Monitoring Site for SD-5.

Photo 1. Sunday River at monitoring site in Reach SD-5 (Outward Bound).

Existing Conditions
- Moderate degree of exposed bedrock throughout reach.
- Some areas of bar formation – typically bed materials quite coarse.
- Some bank erosion and undercutting of trees, resulting in some debris jams.
- Old timber dam present in reach with large amount of aggradation observed upstream of structure.

Summary of Analysis
- RGA (0.59) indicates the channel is *In Adjustment.*
- RSAT (29) indicates that the channel has *Moderate Stability.*

Potential Restoration
- Remove timber dam and replace with rocky ramp riffle structures
- Narrow and redefine channel at dam location
- Local stabilization

Functions Enhanced
- Restore balanced sediment transport through area
- Improve fish passage and habitat
- Stabilize channel to reduce sediment inputs from banks.

Photo 1. Old timber dam observed during field reconnaissance.

Photo 2. Extensive bar that has formed upstream of the timber dam structure.

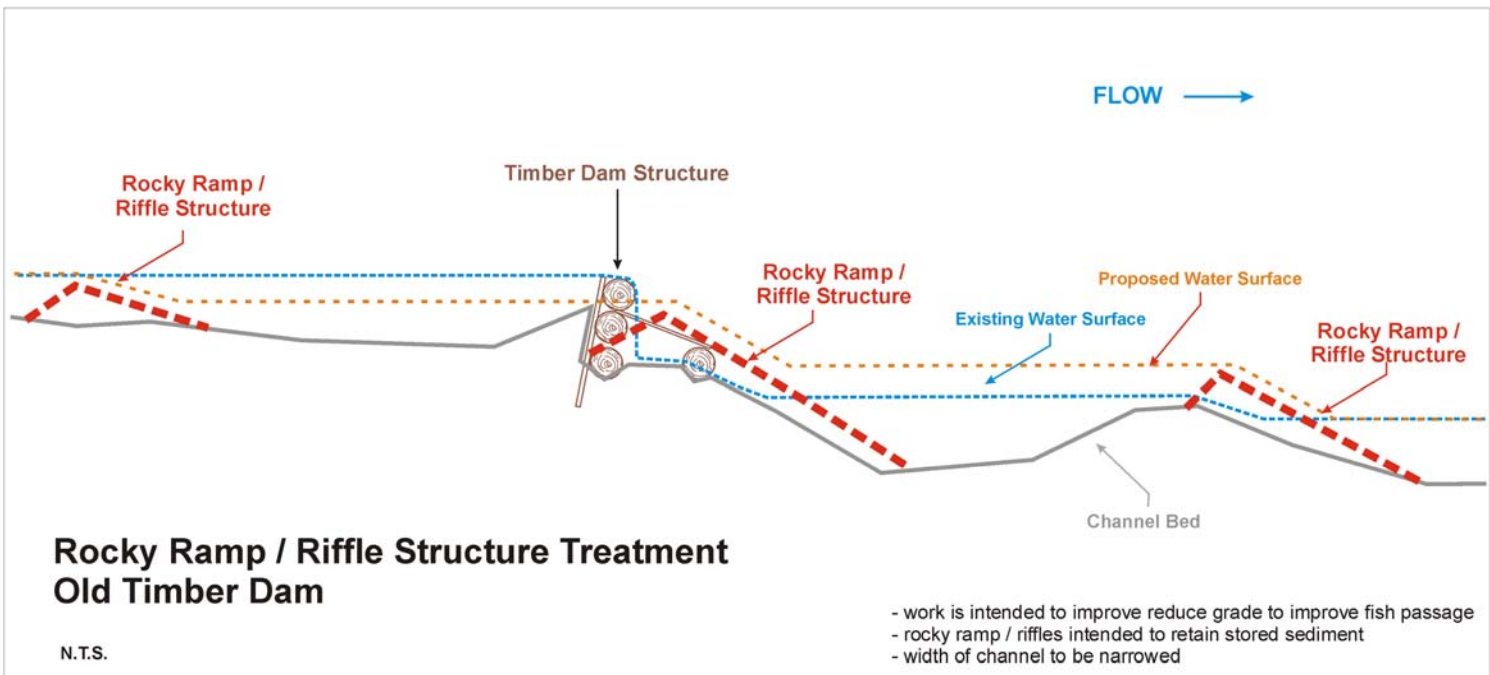


Figure 1. Proposed Rocky Ramp / Riffle Structure channel works to replace existing timber dam.

Existing Conditions

- South Branch of the Sandy River immediately downstream of the headwater confluence area.
- Extensive erosion and avulsions observed during field reconnaissance
- Channel braiding also observed during field reconnaissance.

Summary of Analysis

- RGA (0.66) indicates the channel is *In Adjustment.*
- RSAT (29) indicates that the channel has *Moderate Stability*.

Potential Restoration

- Widen channel to accommodate larger flow events and reduce local erosion.
- Local bank stabilization to reduce sediment inputs (may include re-grading and plantings / live staking or other bioengineering techniques).

Functions Enhanced

- Reduce sediment pulses from upstream areas.
- Reduce sediment input from bank erosion.
- Improved habitat

Photo 1. Severe bank erosion and cobble deposit typical of conditions observed in Reach SD-14 during the rapid assessment.

Existing Conditions
- Steep, bouldery channel.
- Past issues with culvert.
- Culvert is perched, with very steep embankments.
- Channel is over wide downstream of culvert.

Summary of Analysis
- Detailed data collection
- RGA (0.63) indicates the channel is *In Adjustment.*
- RSAT (27) indicates that the channel has *Moderate Stability*.

Potential Restoration
- Structure stability / re-grade embankment.
- Add channel structure (step-pool sequence).
- Re-shape / narrow banks.

Functions Enhanced
- Channel stability.
- Aquatic habitat / fish passage.

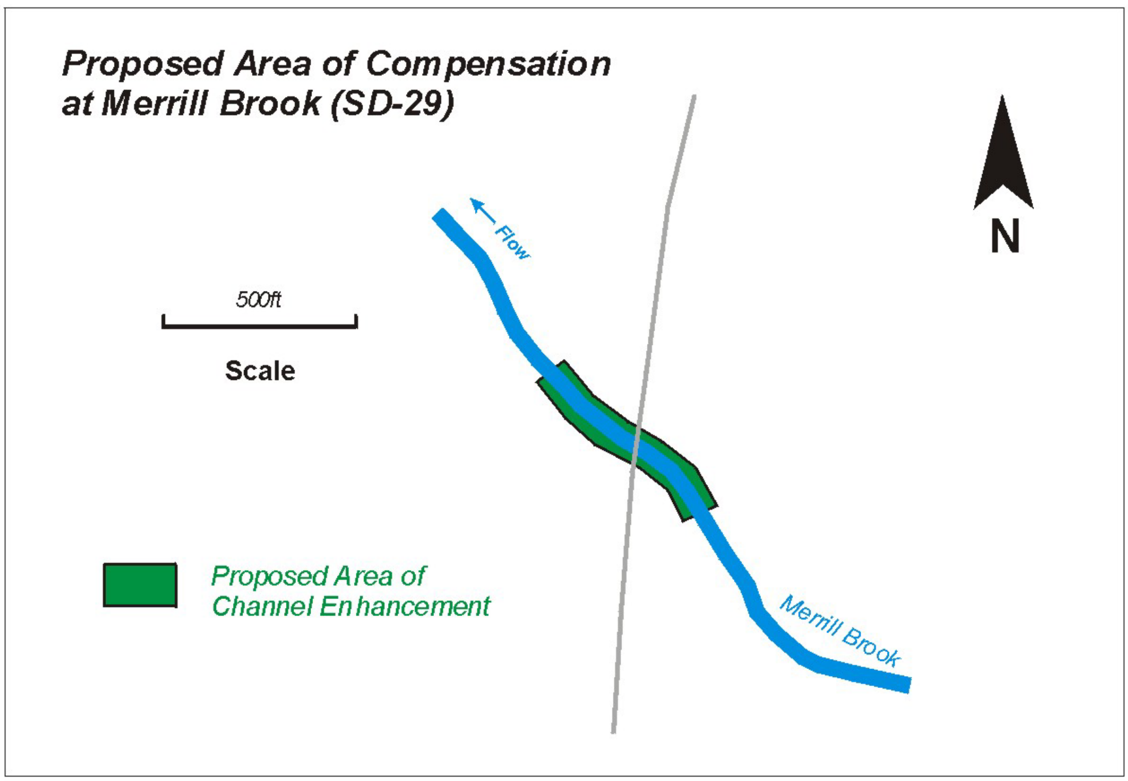


Figure 1. Location of proposed channel enhancements on Merrill Brook (SD-29)

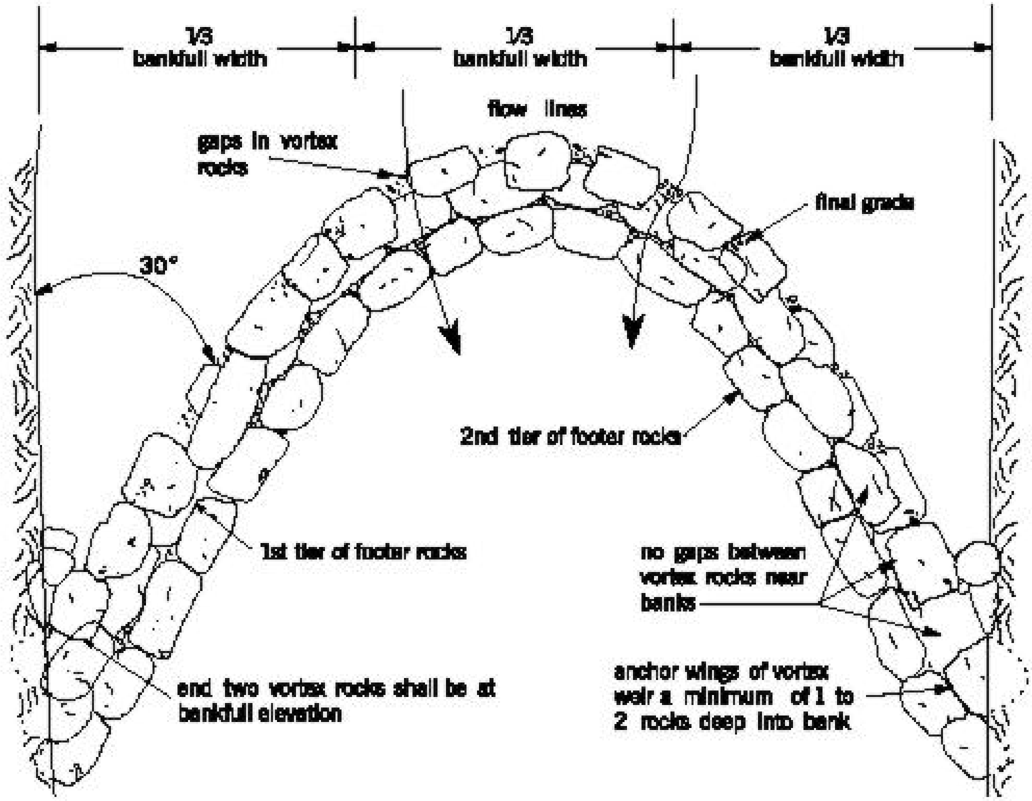


Figure 1. Schematic of a typical Vortex Rock Weir.

Photo 1. Downstream end of Merrill Brook Culvert.

Existing Conditions
- Fish passage issue with culvert at Sunday River Road.
- High deposition area.
- Other areas are entrenched and removed from the floodplain.

Summary of Analysis
- Monitoring site (Control cross-section, Erosion pins).
- Detailed fieldwork collected.
- RGA (0.49) indicates the channel is *In Adjustment.*
- RSAT (26) indicates that the channel has *Moderate Stability*.

Potential Restoration
- Channel design – reconfigure cross-section of channel to improve sediment transport issues.
- Reconfigure channel at culvert – better connect low-flow channel to culvert to improve fish passage.
- Re-grade to connect channel with floodplain and enhance floodplain storage.

Functions Enhanced
- Sediment transport.
- Flood storage.
- Aquatic habitat and fish passage.

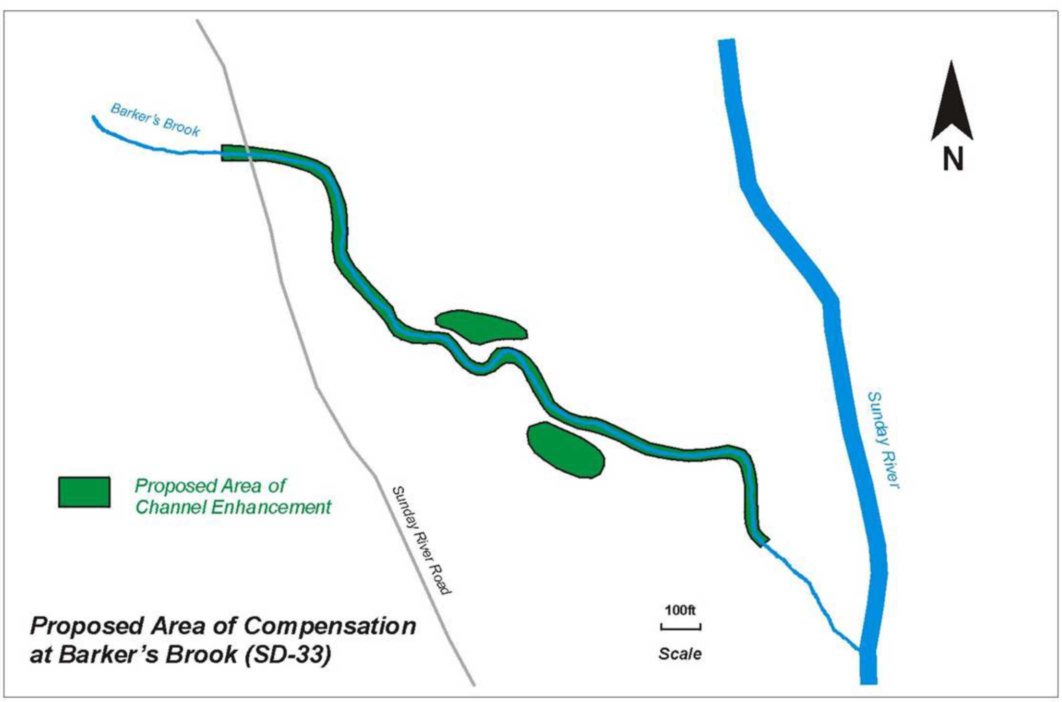


Figure 1. Location of proposed channel enhancements on Barker's Brook (SD-33).

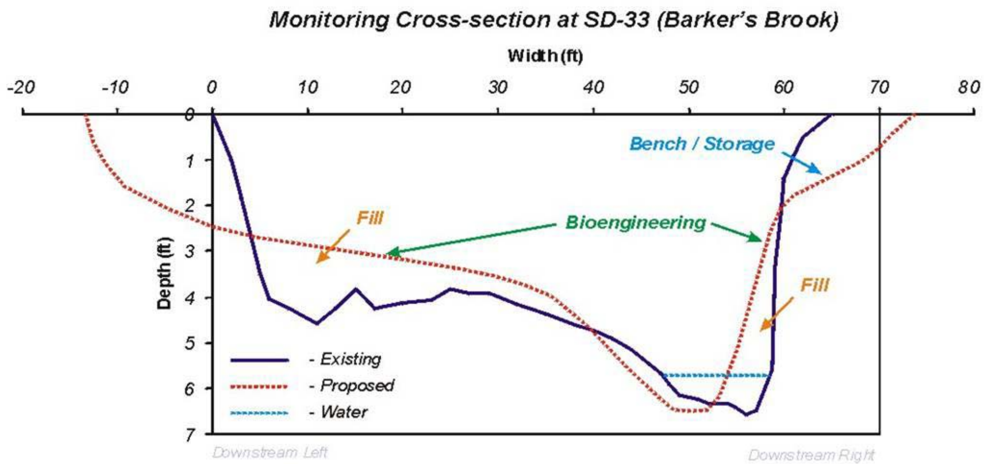


Figure 2. Proposed cross-section at location of existing Monitoring Site for Barkers Brook.

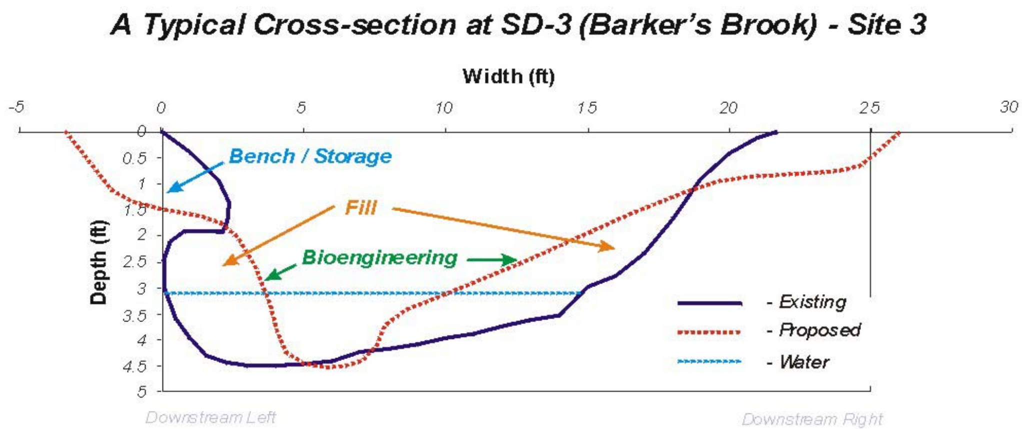


Figure 3. Proposed cross-section adjacent to area of existing pond/wetland feature.

Photo 1. Monitoring site at SD-33 (see Figure 2).

APPENDIX F

Appendix F Restoration Techniques

Numerous bioengineering methods are available to reduce bank erosion while improving channel habitat. The objectives of the restoration project (i.e., habitat improvement, infrastructure protection), scope of work, cost of bank treatment failure (i.e., what is at risk) and resources available will dictate what methods are most appropriate. A series of design details are attached. Bioengineering methods for bank protection presented include simple planting and re-grading, wattles, brush matting, vegetated rip rap, root wads, vegetated cribwalls, and log deflectors. These methods allow bank erosion to be retarded and can also be used to narrow sections of channel to provide increased bed scour and the development of deeper channel pools.

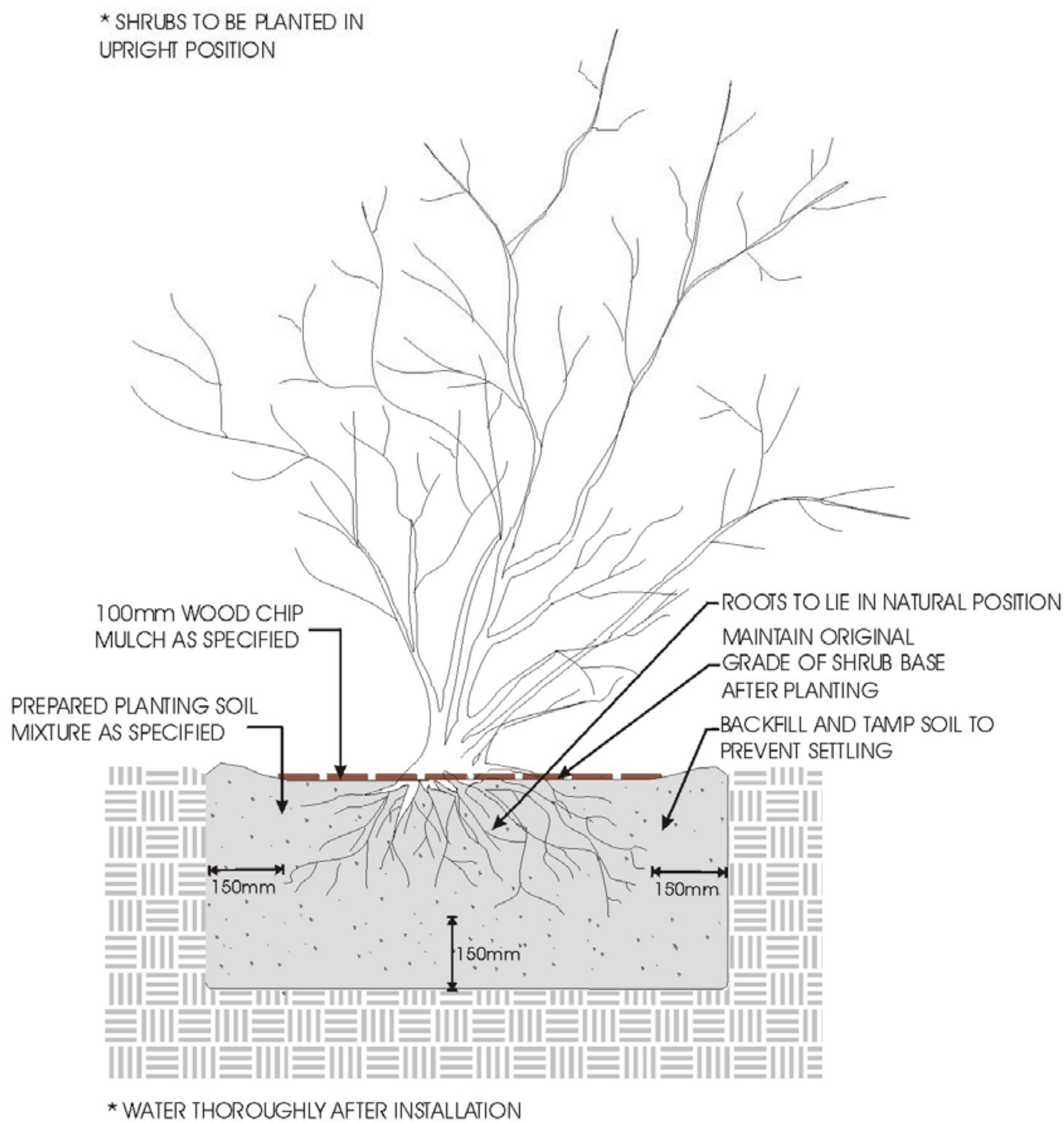
The simplest methods are limited re-grading and bank planting. This simple approach is very economical, installation is not complicated, but has a lower success rate compared to more substantial and structured restoration techniques.

Wattles, brush matting and vegetated rip-rap provide increased levels of bank protection, success rates are higher than simple replanting, but construction work is slightly more complicated and in the case of vegetated rip rap some large machinery may be required. These methods are more successful than simple plantings as they provide initial bank protection to allow vegetation root structures to develop. Wattles and brush matting only require plant materials and are easily installed. These methods provide some habitat benefits, mostly through reduction in bank sediment inputs, decrease in channel width, riparian buffer and channel shading.

Root wads, although not bank protection features, per se, have been used as such. Generally, root wads should be used to provide channel bank habitat. As the root wad creates local flow acceleration and redirection they can exacerbate local bank erosion if not installed correctly. Generally, they need to be used in clusters to provide bank protection and may require additional stone work and riparian planting to be effective. As root wads need to be installed into the bank, some heavy equipment may be required. These features are best used to protect abandoned channels when backfilling will be required and little excavation is necessary. Cribwalls and log deflectors require a similar level of effort, compared to root wads, but provide better bank erosion control.

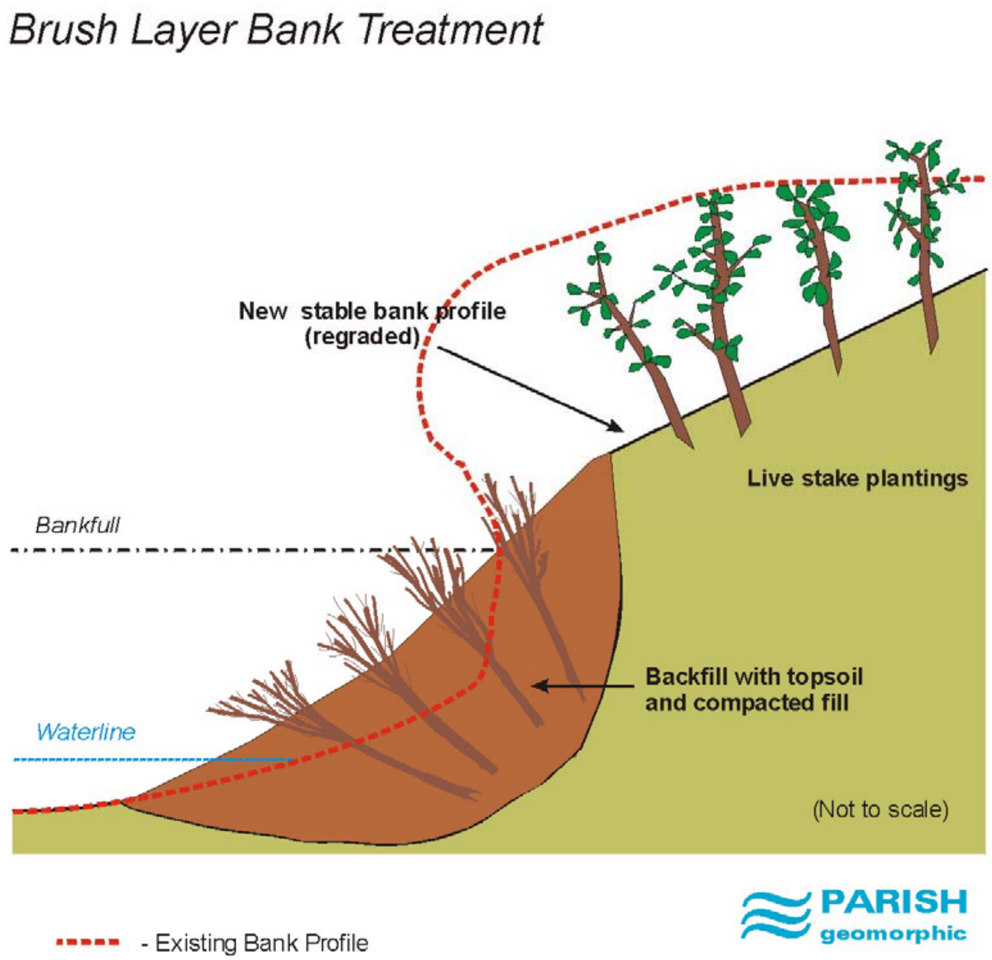
Vegetated crib walls and un-vegetated log deflectors are more complicated structures to install, but they provide substantial bank protection and in the case of the log deflectors train the flow to redirect erosive forces. These structures generally require heavy equipment to install and a skilled operator, and as such, have higher per unit costs and may not be appropriate for volunteer works. The vegetated crib wall is a gravity structure and provides substantial bank protection. Minor undercutting of the cribwall does not overly effect the protection or structural integrity provided, as the support logs act as a cantilever, furthermore the undercutting provides additional habitat. Log deflectors are also built into the bank and therefore have similar performance. These features are less costly than cribwalls, as they are smaller, and may provide additional habitat benefits as they create diverse bank geometry. This in turn contributes variability to channel habitat. Some care in the placement of these structures is needed as they redirect flows and can create additional, and in many cases unexpected, erosion issues. Aggressive bank plantings should accompany these structures to reduce the chance of undermining or out flanking.

In many cases, entrenchment will need to be addressed along with the problem of bank erosion. The cumulative erosive forces on channel bed and bank are reduced by improving connection to the floodplain. Along with re-grading of banks, instream structures such as riffles, cross-vanes and cascades will need to be established. Many of these structures can be installed with physical labour; however, machinery may be needed depending on the size and amount of material required.



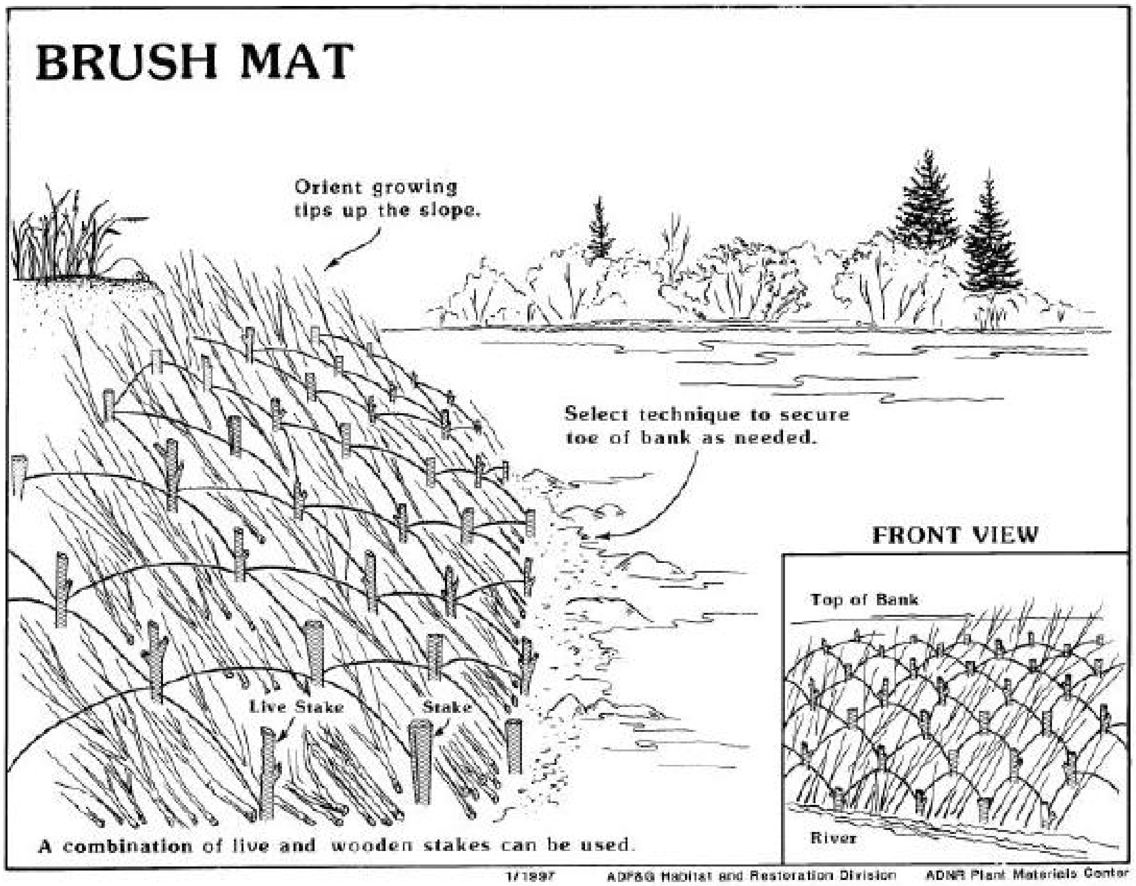
BARE ROOT SHRUB TYPICAL DETAIL N.T.S.

Bare Root Shrub Detail

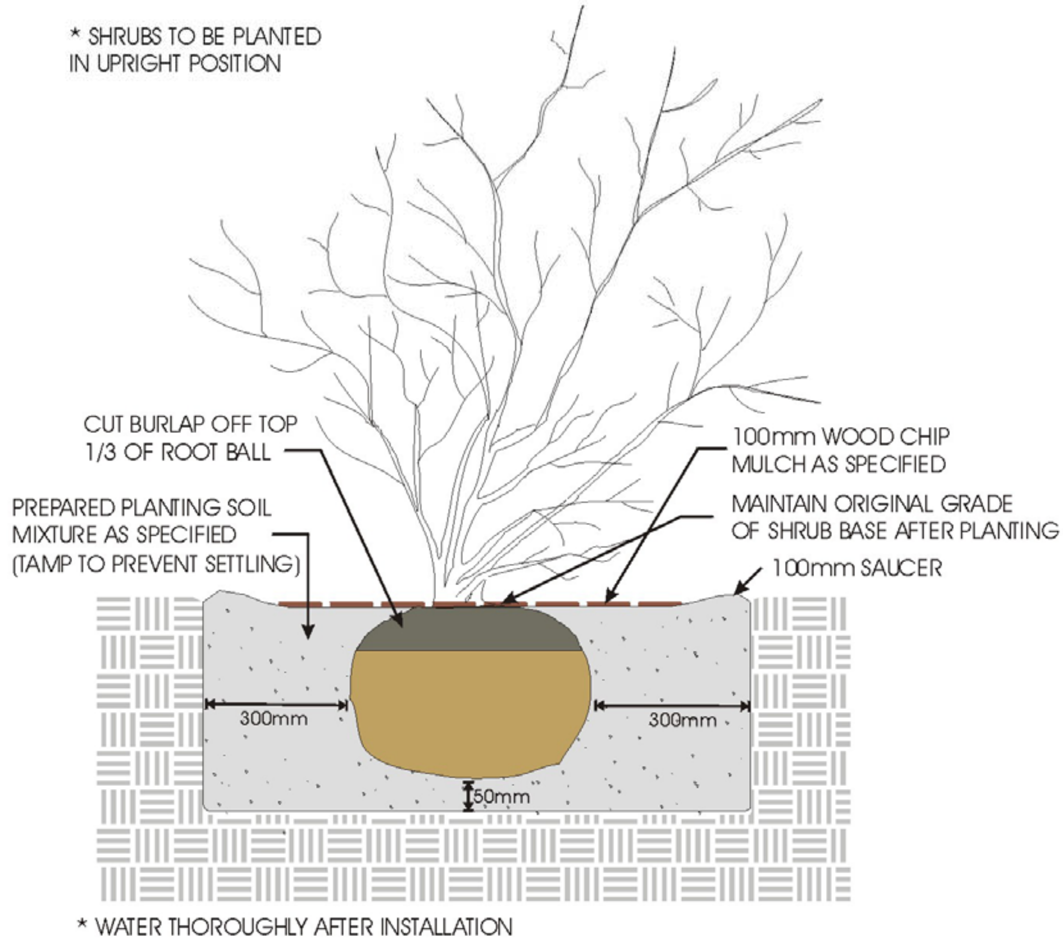


Brush Layering Bank Treatment N.T.S.

Brush Layering Detail

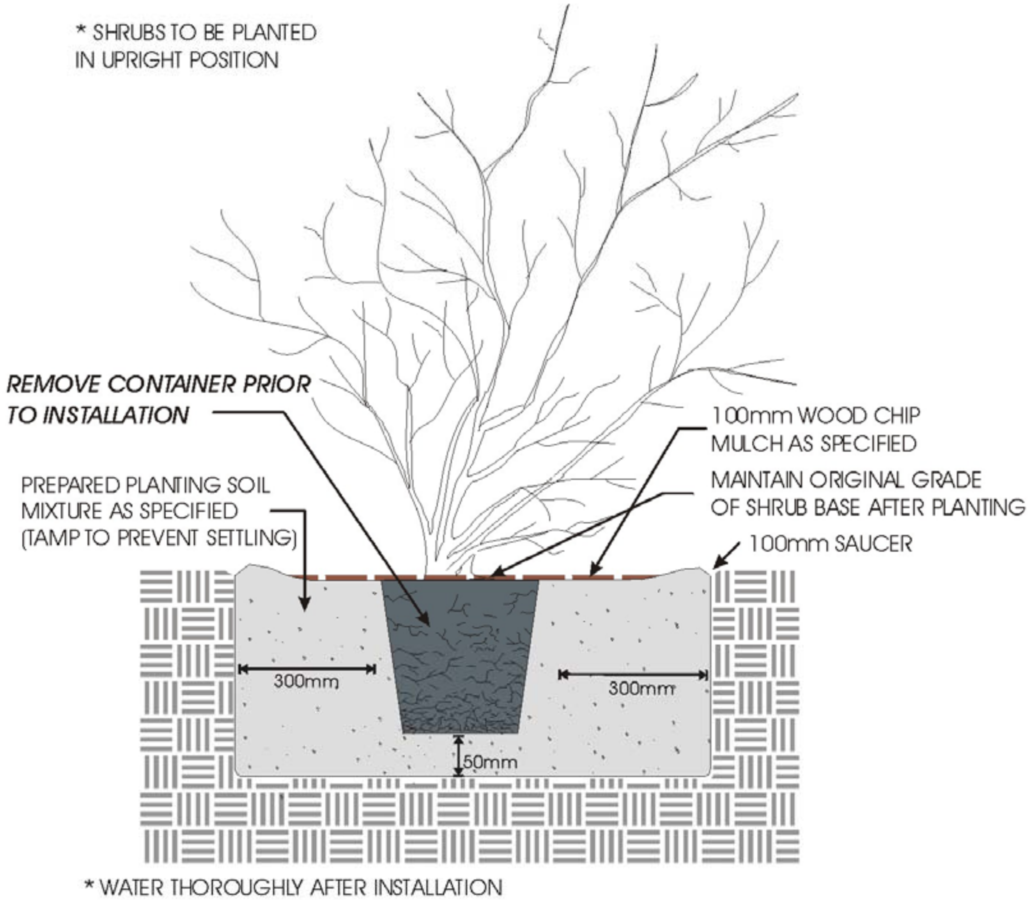


Brush Mat Detail



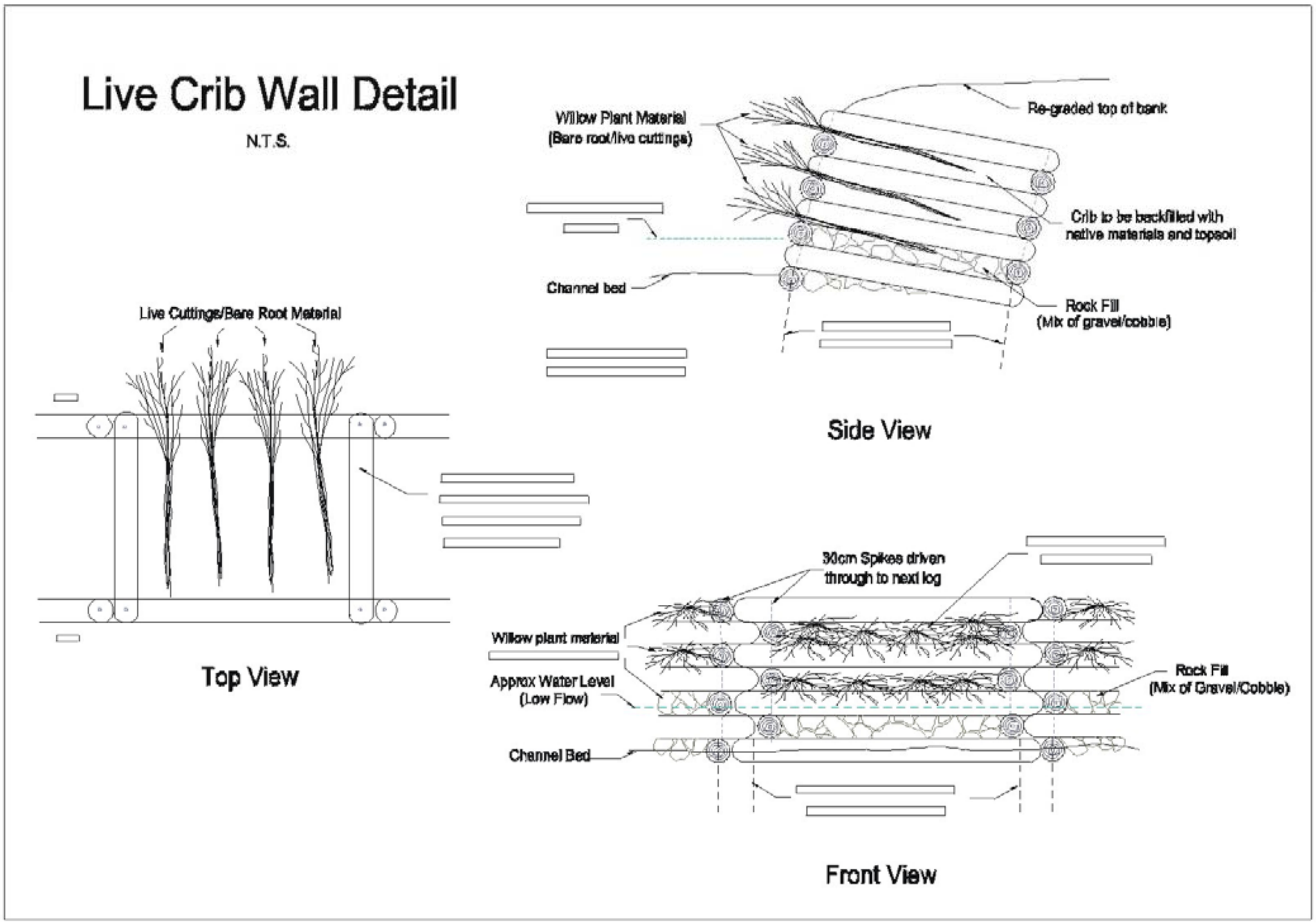
BALLED AND BURLAPPED SHRUB TYPICAL DETAIL N.T.S.

Balled and Burlap Shrub Detail

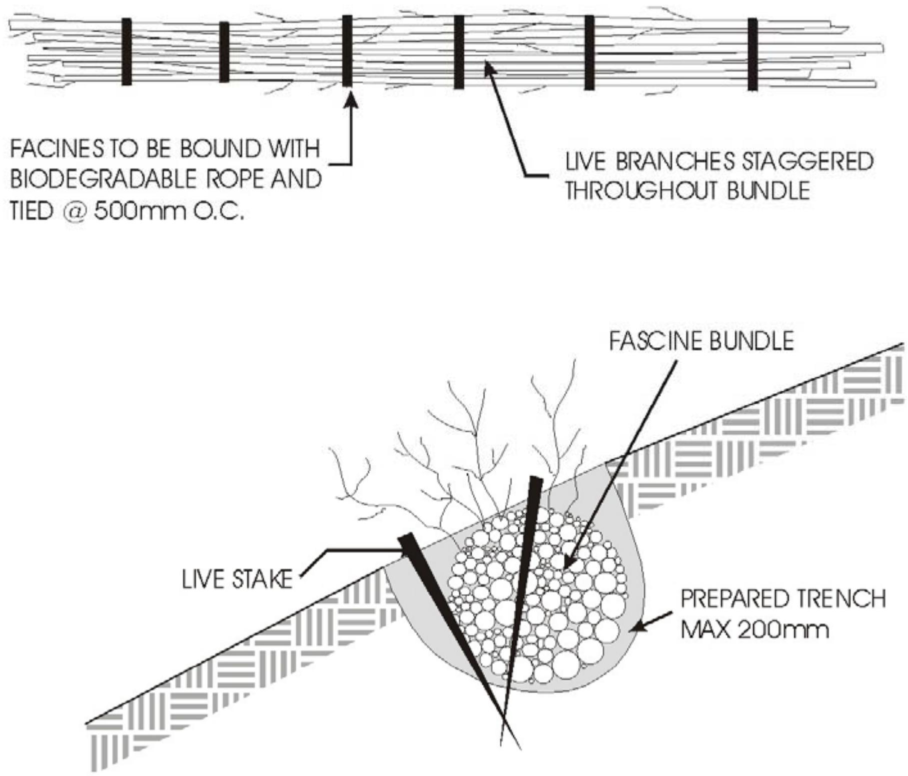


CONTAINER GROWN (C.G.) SHRUB TYPICAL DETAIL N.T.S.

Container Grown Shrub Detail

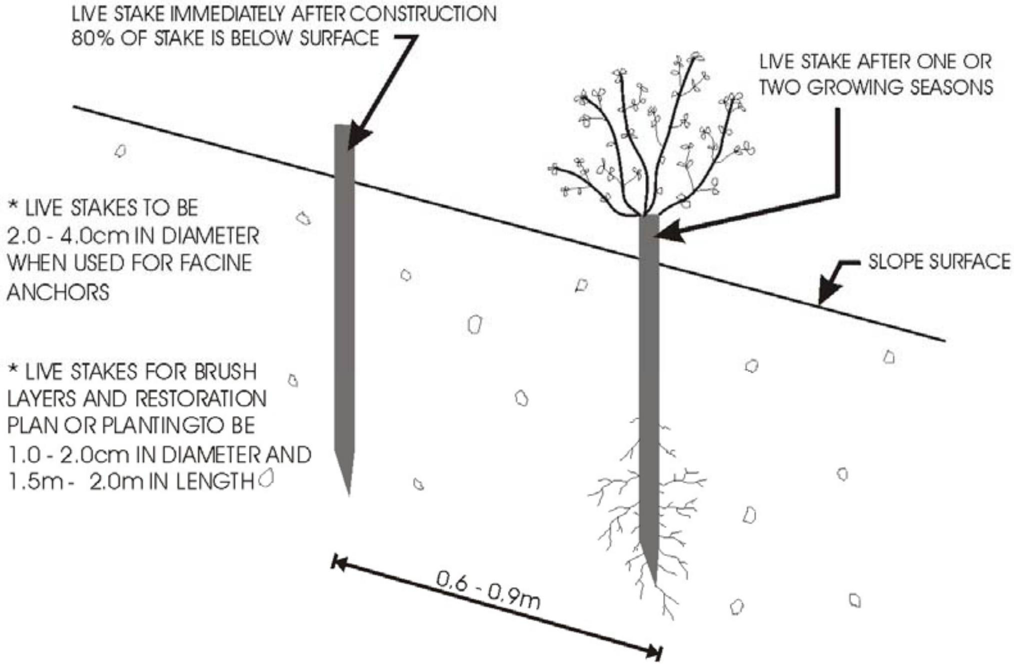


Vegetated Cribwall Detail



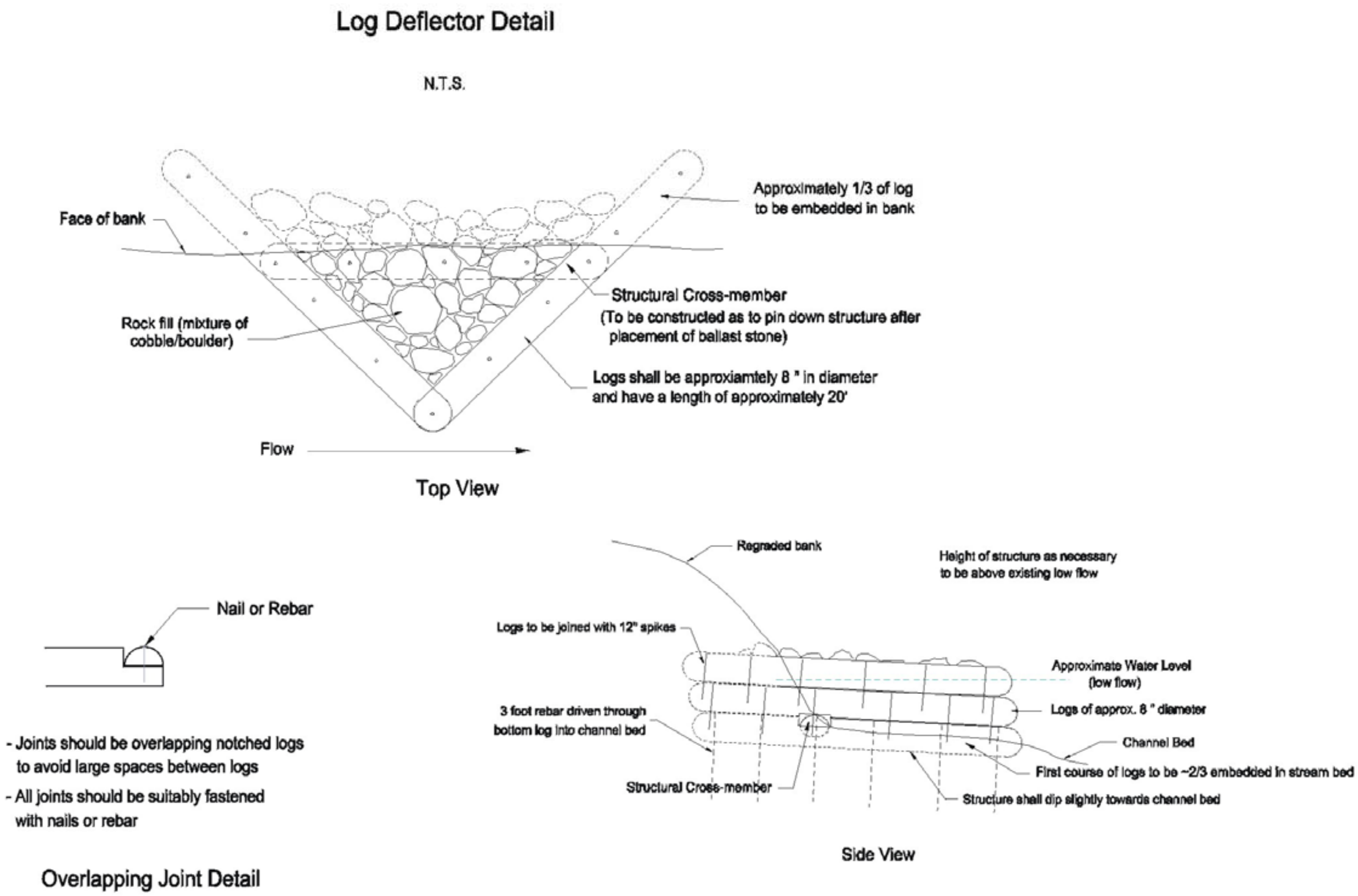
FASCINE BANK TREATMENT DETAIL N.T.S.

Fascine Detail



LIVE STAKE INSTALLATION DETAIL N.T.S.

Live Stake Installation Detail



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Log Wing Deflector Detail

Typical Vortex Rock Weir

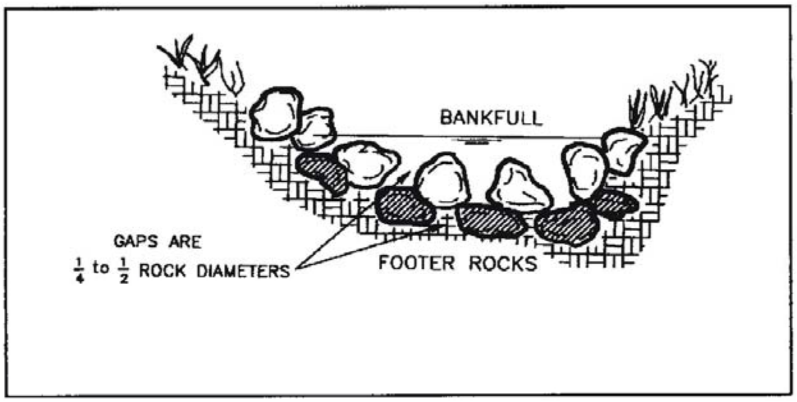

Figure 1: Vortex rocky weir, cross-section view (Rosgen,1993).

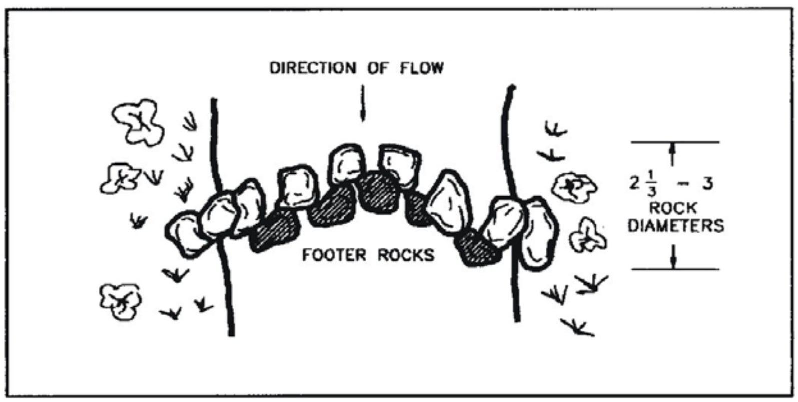

Figure 2: Vortex rocky weir, plan view (Rosgen,1993).

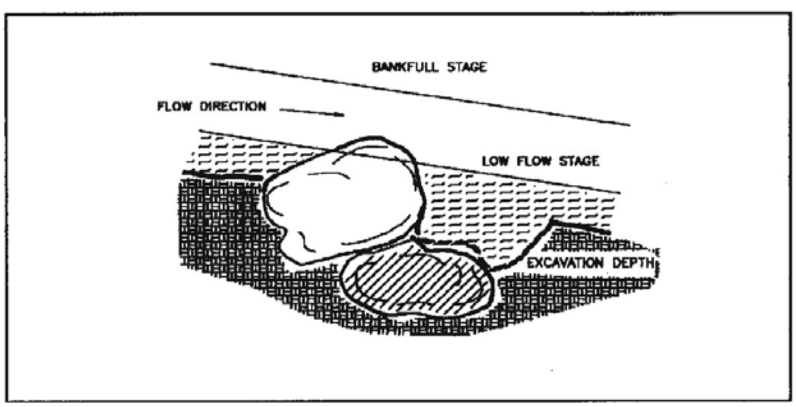

Figure 3: Vortex rocky weir, profile view (Rosgen,1993).

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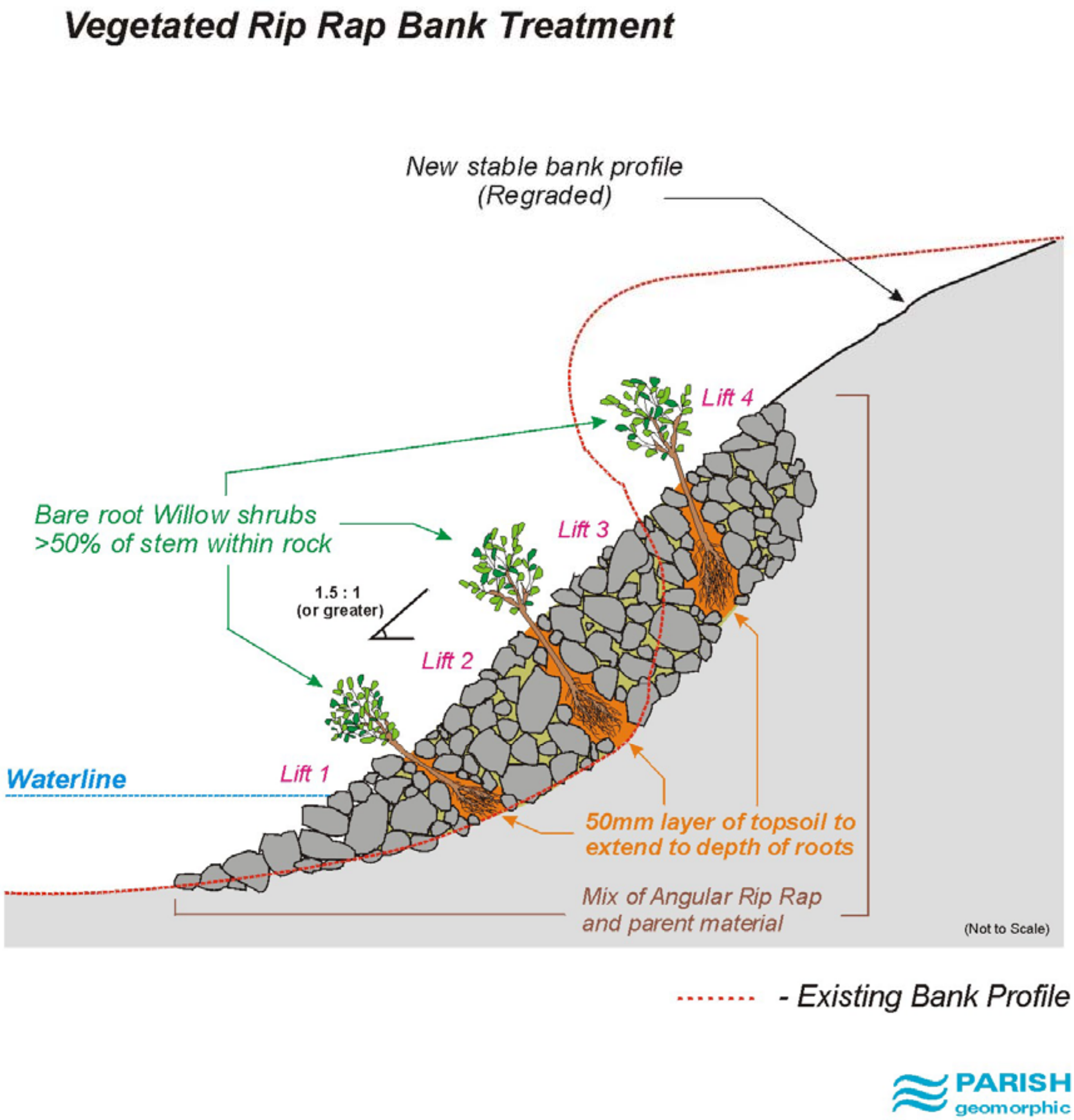
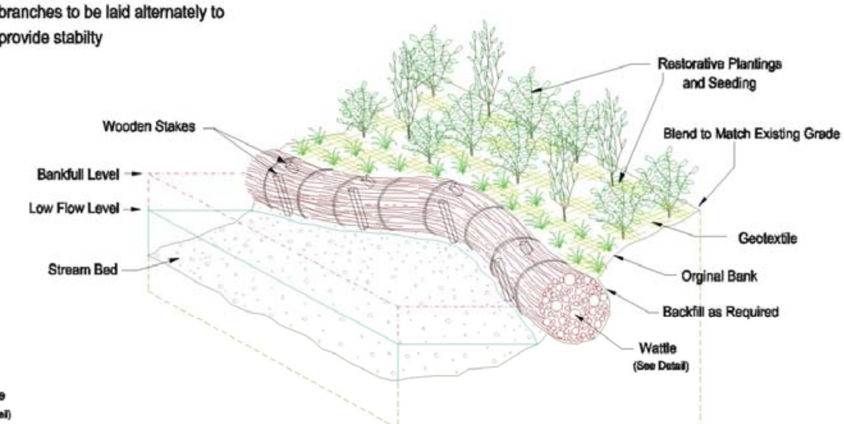
Vortex Rock Weir Detail



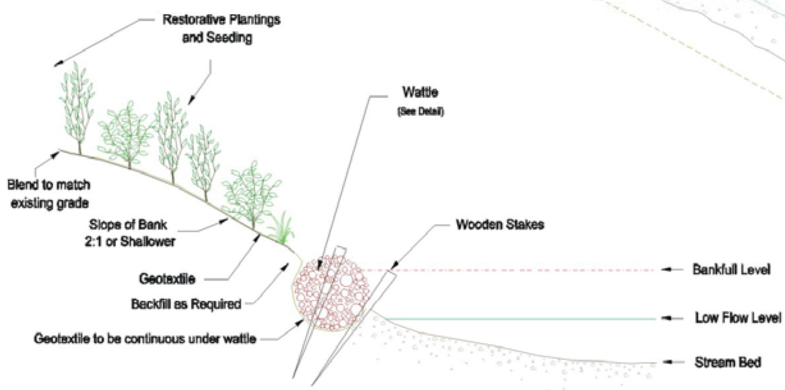
Vegetated Rip Rap Detail

Wattle Detail
(N.T.S.)

- approx. 20 - 25 cm diameter
- tie bundle every 30 - 45 cm
- bundle to be constructed with branches of live mixed willow species
- branches to be laid alternately to provide stabilty



Wattle Installation
(Isometric View)
(N.T.S.)



Wattle Installation
(Section View)
(N.T.S.)

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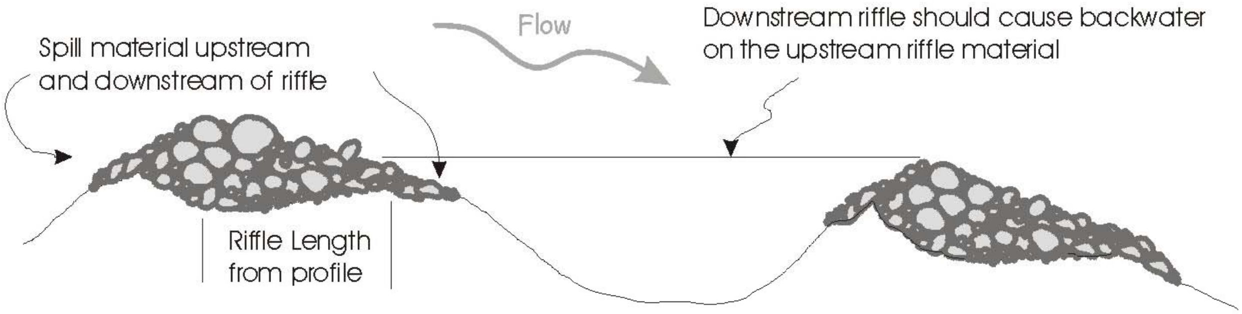
Wattle Detail

Riffle Construction Notes

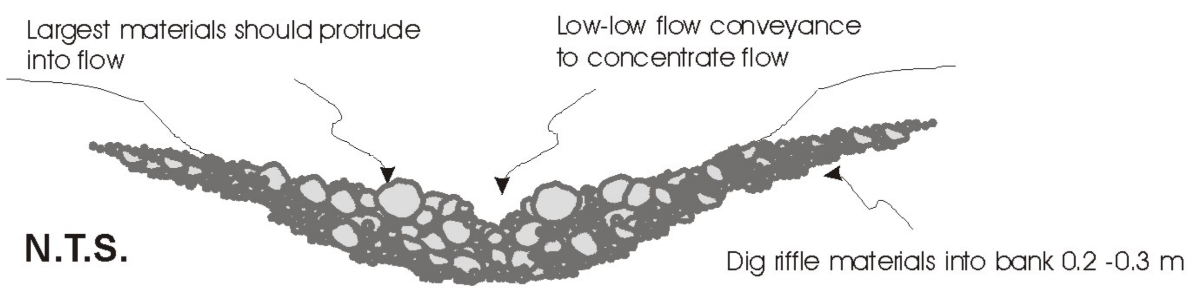
Typical Riffle Sequence in Profile



N.T.S.

- Dig depressions into the bed to stabilize riffle materials
- Place largest material (key stones) at riffle crest (i.e. highest point)
- Ensure that largest rocks protrude into flow
- Thickness of riffle substrate at crest is 2-3 times the largest material
- Mix substrate with pit run and/or native materials to fill voids in riffle
- Taper grain size and bed thickness downstream and upstream of crest
- Riffle materials should extend over the lip of the depression
- Spread remaining rock on riffle to attain riffle angle
- Riffle length is determined from profile
- Substrate to be placed directly on natural materials (i.e. do not use filter cloth)

Riffles in Cross-section



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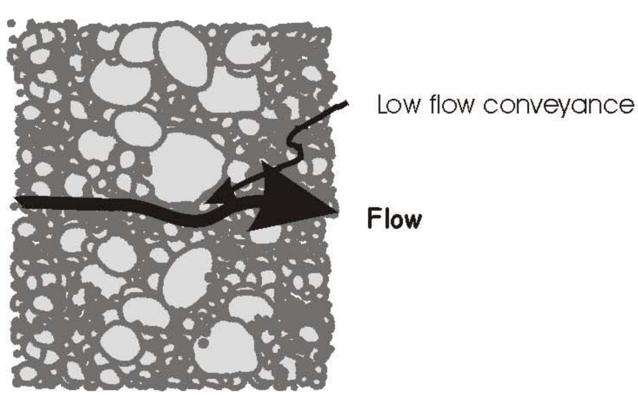
Riffles in Profile



N.T.S.

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Riffle Construction Detail

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